A CAUSAL ANALYSIS OF THE RELATIONSHIP BETWEEN ATTENTION AND MEMORY FROM ADOLESCENCE TO OLD AGE

BY

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1985

ACKNOWLEDGMENTS

I wish to express deep gratitude and warmest appreciation for the chairman of my supervisory committee, Dr. Walter R. Cunningham. He has provided support, guidance, and direction for my professional growth. I am very thankful for his sincere interest, and for his friendship. Appreciation is also extended to the supervisory committee members, Dr. W. Keith Berg, Dr. Richard Griggs, Dr. Patricia Miller, Dr. Scott Miller, and Dr. Mary Lou Koran, for their assistance and support throughout this project.

My thanks are also extended to the staffs of Newberry Junior Senior High School, Oak Park, and the 400, and to William Haber and Robin West for their direct and indirect assistance in the data collection aspects of this project.

Finally, a special kind of appreciation is extended to my friends and fellow graduate students whose support has motivated me to persevere, and who always believed I could do it.

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Abstract of Thesis Presented to the Graduate Council of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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August 1985

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Age differences in memory performance, with young adults performing at a level superior to elderly adults, are a consistent finding in the psychology of aging. Similarly, elderly adults perform less well than young adults on tests of attention and vigilance. It has been suggested that attentional problems among the elderly may be causally related to the memory problems which are commonly observed. Causal modeling procedures provide statistical tests to assess whether a proposed model acceptably fits the covariance patterns underlying a data set. The present study undertook an age comparative causal analysis of memory, attention, and vigilance indicators in order to determine whether elderly adults are more reliant upon attention and vigilance for adequate

memory than are young adults. The subjects were 98 adolescents and 140 senior citizens.

The primary analyses indicated that the constructs of interest were not comparably represented in the two diverse age groups. Therefore, the hypothesis of interest, that the causal parameters connecting attention and memory, and vigilance and memory, in the older group would be statistically greater than in the young group, could only be tentatively evaluated. This analysis indicated that these parameters were statistically equivalent, contrary to the hypothesis, but given the lack of age comparative construct validity, such a result may be a statistical artifact. Subsequent analyses indicated that only two factors were needed to explain the correlations among the indicator variables in the young subjects while between three and four were needed in the older subjects. An additional age sensitivity analysis demonstrated that older subjects are particularly impaired on speeded tests of attention as well as on free recall and paired associate tests, a finding which is congruent with previous literature. These results underscore the necessity of demonstrating age comparative construct validity for measures of interest when comparing young and elderly subjects on cognitive processing tests.

CHAPTER I
INTRODUCTION AND OVERVIEW

Age differences in memory are among the most consistently reported cognitive deficits associated with advancing age (cf Craik, 1977, and Smith, 1980 for reviews). This phenomenon is typically manifested as a significant age difference in free recall performance, although age differences in recognition and cued recall have also been noted. Similarly, memory complaints increase with age (Kahn, Zarit, Hilbert, & Niederehe, 1975). Research has focused upon identifying the locus of these age differences, generally within the serial information processing orientation (Atkinson & Shiffrin, 1968) or levels of processing orientation (Craik & Lockhart, 1972). Failure to perform adequately is usually attributed to inappropriate or insufficient processing at encoding, inadequate retrieval processes, or both. Unfortunately, encoding and retrieval cannot be unequivocally assessed independently of one another, rendering definitive conclusions about precise processing deficits in remembering among older adults difficult, at best. It may be that these research endeavors have reached a relatively dead end.

Recently, several investigators have proposed that attentional problems may contribute to older adults' difficulties on laboratory memory tasks. Craik and Simon (1980) proposed that older subjects have a reduced supply of processing resources, and are thus likely to perform more poorly on cognitive tasks which require much "cognitive energy," which must certainly include recall of, for example, unrelated word lists. Thompson (1980) suggested that periodic lapses in attention are a correlate of memory problems among the elderly. These suggestions have an intuitive appeal: if a subject, of whatever age, fails to focus appropriately on incoming stimuli, he is less likely to optimally encode and store the information than a second subject who succeeds in encoding; the first will thus perform more poorly at test time. Also, monitoring internal processing, such as rehearsal or memory search during retrieval, requires processing resources (Hoyer & Plude, 1980); a reduction in these resources, i.e., a reduction in attention, will produce less adequate monitoring and less efficient processing (Hasher & Zacks, 1979; Keele, 1973). If it can be demonstrated that older adults do, in fact, have reduced processing resources, are unable to focus effectively on relevant stimuli and filter out irrelevant stimuli, and have increased difficulty monitoring internal processing, it might also be

demonstrated that attentional deficits are useful as an explanatory construct for understanding memory performance age differences in the elderly.

The purpose of the present research is to test a causal model of the relationships among attention, vigilance, and memory performance in both young and elderly adults. Vigilance is considered to be a form of sustained attention (Bakan, 1955) or tonic alertness (Posner, 1978), and is necessary for maintaining continuous attention throughout the performance of a given task. Although the research literature is scanty, there have been suggestions that older subjects perform more poorly than younger subjects when the vigilance task is only ten minutes in length, with increasing age differences in percent correct and false positive responses from the beginning to the end of the task (Harkins, Nowlin, Ramm, & Schroeder, 1974). It would be expected that measures of vigilance and attention would be related to memory performance. The proposition that age differences in vigilance and attention account for some proportion of age differences in memory, and are causally related to such age differences in memory, rests upon the following rationale. Certain changes in the central nervous system (CNS) with increasing age have been well documented. For example, with increasing age there is linearly increasing cell loss until approximately age

60, following which the cell loss increases exponentially (Brody, 1976). That behavior is tied to the integrity of the CNS has been proposed by Birren, who believes that general slowing, attributable primarily to central nervous system changes, is fundamental to various age-related cognitive deficits (Birren, 1974; Birren, Woods, & Williams, 1980). Specifically, localized cell loss and deterioration in the reticular formation and frontal cortex have been proposed as underlying age-related deficits in vigilance and attention, respectively (Brody, 1973; Albert & Kaplan, 1980). In particular, these CNS changes have been proposed to account for the aging individual's increased distractibility, decreased ability to sequence tasks, and decreased alertness, i.e., decreased attention (Terry, 1978).

Causal modeling techniques (Kenny, 1979) provide statistical procedures for determining whether one's data are consistent with a hypothesized model. These procedures require that the proposed model is based upon a priori reasoning which includes a rationale for the causal ordering of the variables, and upon either a reasonable theory concerning the phenomena under investigation or previously accumulated compelling empirical evidence regarding the proposed relationships. One cannot prove that a given model is correct; one is only permitted to state that the data

are consistent with it. If a suitable fit is demonstrated between data and model, the hypothesized causal mechanisms gain credence in terms of the theoretical explanation of the phenomena under consideration, which might then be further tested in an experimental investigation with an independent sample of subjects, with possible additional confirmation, disconfirmation, or modification.

The following chapters provide a detailed description of the relevant literature, the rationale and hypotheses, methodology and analyses, results, conclusions, interpretations, and implications. Chapter II provides a selective review of the research literature which is relevant to the development of the proposed model, i.e., memory and aging; attention, vigilance, and aging; evoked potentials and aging; and the neurophysiology of aging. Chapter III provides a concise rationale for the proposed model, based upon the literature surveyed in the preceding chapter. The specific hypotheses are presented along with a detailed description of the model. Chapter IV provides a description of the methodology: subjects, tasks, and procedure. Chapter V describes the data analyses and results, while the final chapter presents a discussion of the results, interpretations, and implications thereof.

CHAPTER II
LITERATURE REVIEW

This chapter presents a selective review of the empirical literature which is relevant to the development of the proposed model. Where appropriate, comments on the dominant theoretical approaches to certain topics are included. It should be emphasized at the outset that the research literatures being surveyed are in some cases vast, and great selectivity has been exercised in excerpting the most representative studies for inclusion.

Memory

Theoretical Considerations

During the last decade the majority of investigations in the field of memory and aging have been conducted within the orientations of either serial information processing (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965) or levels of processing (Craik & Lockhart, 1972; Craik, 1977). The former posits separate "stages" of processing or memory "stores", usually distinguished by their time parameters, capacity, and encoding characteristics. For example, visual sensory memory (iconic memory) is thought to

last for perhaps 500 msec, to have a relatively large capacity, and to contain unanalyzed physical copies of stimuli. The next stage is referred to as short term or primary memory, with a limited capacity [Miller's magic number 7 $\pm$ 2 (1956)], in which active processing facilitates transfer to the third, presumably unlimited long term or secondary memory.

This three-stage approach has served as a very general theory which has integrated a large body of research on memory, and has provided a springboard for investigators of age differences in memory. However, critics have suggested that the distinction between memory stages is too simplistic and artificial (Klatzky, 1980). Discontent with the stage approach prompted Craik and his coworkers to propose that memory should be considered to be a continuum rather than a set of discrete stages. The durability of a memory trace is thought to be a product of both the "depth" of processing, or the qualitative analysis, and the "elaborateness", or extensiveness of processing carried out at a given level. Furthermore, it is assumed that retrieval information must also be processed in a deep and elaborate fashion at recall, matching encoding operations, in order to achieve optimal performance.

Both of these orientations, the stages and the levels of processing approaches, have dominated research on memory and aging, with the latter probably

being currently the most popular approach. The results and conclusions of several studies will be described below. However, it should be noted that the levels of processing approach is not without its detractors. Brown (1979) observed that classifying particular tasks as semantic, e.g., is not straightforward. Certain tasks may be performed in various ways, and instructing a subject to engage in a particular operation does not guarantee that he will do so. Also, "deep" processing is typically the sort that allows one to perform well on a laboratory memory task; it is assumed that good performance on a free recall task following incidental orienting task completion reflects deep, semantic processing. This is circular and post hoc reasoning. Since semantic processing is asserted to result in efficient retention, the observation that a particular orienting task results in good retention is taken to indicate that semantic processing must have been engaged in. Eysenck (1978) has also suggested that no suitable criteria are available for indexing either the depth or elaborateness of encoding, and that encoding processes are irrelevant to the determination of retrieval strategies or decision processes necessary for both recognition and recall.

Age Differences in Memory Stages

Age differences in sensory memory have received limited attention by researchers. Age differences are

noted in the amount of and rate at which information is extracted from the icon: older adults require 30% more processing time to construct the icon, which then persists for a shorter duration; older adults need as much as 80% more processing time to extract information from the icon and recode it into short term memory (Cerella, Poon, & Fozard, 1982). Walsh and Prasse (1980) also concluded that older adults require more time to read out information from the icon, and suggest that this slowing is attributable partly to slowing pattern recognition processes and partly to attentional deficits, such as slowing of an attention switching mechanism (Walsh & Thompson, 1978). Auditory sensory memory (echoic) has not been explicitly investigated among older adults (Crowder, 1980). Craik (1977) reviewed the dichotic listening studies which included adults of different ages, in which echoic memory may be implicated. It has been suggested (Inglis & Caird, 1963) that the second half-set, or information from the second ear reported, is held in echoic memory while the first half-set is being reported, and that the information in the second half-set decays more rapidly with age. Although no direct support has been found for this hypothesis, it is possible that slowing or impairment of an attention-switching mechanism, such as has been suggested to account for age differences in iconic memory, may also be implicated in the poorer

performance of older subjects in reporting the second half-set in dichotic listening studies.

Age differences in primary memory capacity appear to be minimal. Primary memory is considered to be involved when material is still at the focus of conscious attention, being rehearsed or operated upon by other control processes. Memory span studies, such as those using the WAIS forward digit span subtest, indicate that age differences are slight. However, if divided attention or reorganization of the material is required, greater age differences are observed (Hartley, Harker, & Walsh, 1980). When response latency is measured, as in the Sternberg (1969) memory scanning task, older subjects require more time for detection and encoding of the probe, searching the contents of primary memory, and response selection and execution (Anders, Fozard, & Lillyquist, 1972; Ford, Roth, Mohs, Hopkins, & Koppell, 1979). Thus, while the number of items retrieved from primary memory remains relatively stable with increasing age, the speed of retrieval appears to decline.

Age differences in secondary memory have been, in contrast, consistently reported. The prototypical laboratory task is to instruct subjects to learn lengthy lists of unrelated words in preparation for a subsequent memory test. When the test is free recall, older subjects always remember, on average, fewer words

than younger subjects. When the test is recognition, age differences are still generally noted, although they tend to be smaller in magnitude. If the test is cued recall, the results vary, depending upon the nature of the cue (e.g., orthographic vs semantic) and whether the cue is present at encoding as well as at test time. Smith (1977) reported results in which age differences were eliminated when the cues were semantic (category labels) and were present at encoding. The general result, however, is that age differences are attenuated during cued recall tasks rather than eliminated (see Burke & Light, 1981, for a review).

Having established that there are age differences in secondary memory performance, researchers have been attempting to identify the specific nature and locus of the age-related decrements in performance. Fifteen years ago it was assumed that older subjects had problems only with retreival. This conclusion was based on the results of Schonfield and Robertson (1966), who found that memory for lists of unrelated words was unimpaired across the life span when tested with recognition. However, the linear decrease with age in free recall suggested that, although acquisition and storage were equivalent (the recognition results), older adults have a retrieval deficit. Subsequent research has shown that recognition performance is not unimpaired in older subjects, however. The finding

that recognition performance is less impaired than free recall performance suggests that both acquisition and retrieval problems are involved in observed age differences in memory performance.

Research on acquisition has focused on the strategies which subjects use in learning word lists. Temporal differences in rehearsal have been identified, with older adults requiring more time to rehearse a single item (Salthouse, 1980). Rehearsal strategies of older subjects often consist of only single repetitions of each item as it is presented, while young subjects show categorical organization when the list structure permits such strategies (Sanders, Murphy, Schmitt, & Walsh, 1980). Age differences in subjective organization for lists of unrelated words have also been reported (Hultsch, 1971, 1974), with concomitant age differences in recall performance. Older subjects often fail to use mnemonic strategies, such as imagery, spontaneously (Whitbourne & Slevin, 1978); when explicit instructions to form images are given, all age groups improve, with age differences in performance remaining (Burke & Light, 1981). Only when imagery instructions have been combined with a long response interval, as in the paired-associate study reported by Treat and Reese (1976), have age differences been eliminated.

The research efforts described above have identified many specific problems experienced by older adults confronted with laboratory memory tasks. However, explanatory mechanisms have not been satisfactorily specified. The most popular explanations have been of two kinds. The first are noncognitive, such as differences in formal education, anxiety, cautiousness, and motivation. As Burke and Light (1981) have noted, these explanations "predict age differences across the board and cannot readily accomodate findings of small age differences in some types of memory tasks and larger differences in others" (p. 513). A more plausible noncognitive explanation has been that the slowing of both the peripheral and central nervous system underlies age differences on various cognitive tasks. General behavioral slowing is thought to be tied directly to neuronal cell loss and deterioration associated with advancing age (Brody, 1976; Scheibel & Scheibel, 1975). Waugh and Barr (1980) have proposed that age-related memory deficits can be accounted for by the reduced speed of information processing, affecting all processes involved in memory performance. This view is not incompatible with the proposed model; among the processes involved in performing a memory task are attentional focusing and filtering, and monitoring.

Slowing of attentional mechanisms may in fact contribute to age differences in memory.

The main cognitive explanation offered is that older adults have a processing deficiency. This idea comes from the child development literature (Flavell, Friedrichs, & Hoyt, 1970). It is suggested that older adults are less likely than young adults to spontaneously utilize strategies that are optimal for encoding and retrieving information, even though the strategies may be known to them. According to this view, age differences should be reduced or eliminated if older adults can be induced to adopt these strategies through instructions or training. However, the evidence to date suggests that age differences remain. It should be noted that even if the production deficiency hypothesis had been supported, it would still not serve as a satisfactory explanatory mechanism unless the production deficiency could be further explained by some other mechanism.

Researchers have concluded that strategy training procedures do not effectively control the nature of subjects' operations, and have turned to the levels of processing approach because of the attractiveness of bypassing this issue (Burke & Light, 1981). In the levels of processing studies, subjects are instructed to perform specific operations on the material in the guise of incidental orienting tasks in an effort to

control the amount and kind of processing that is carried out. As will be seen below, the essential question of the precise nature of older adults' memory problems has not been satisfactorily answered by research in this direction.

Age Differences in Levels of Processing

Given the assumption that acquisition operations vary on a continuum from shallow to deep or semantic processing, investigators typically design several incidental orienting tasks which are assumed to control the amount and kind of processing engaged in. Subjects do not expect a subsequent memory test. An intentional learning condition is usually included to provide a comparison of the effectiveness of the orienting tasks in controlling processing relative to standard laboratory tasks, in which processing strategies are uncontrolled. Examples of shallow processing tasks are to indicate whether a given item contains an "m" in its spelling, or whether it is printed in upper or lower case letters. An intermediate or phonemic level task would be to indicate whether a given word rhymes with, for example, "light". Examples of deeper or semantic processing tasks are to determine what part of speech a given word is, or whether it is from the category of animals. The latter tasks require the subject to determine the meaning of the word by accessing stored semantic information. The logic of assessing age

differences following incidental orienting tasks is as follows. By controlling the operations subjects are engaging in, it is assumed that acquisition is equated across age groups. If age differences remain on a later free recall test, they may be attributed to processes associated with retrieval. Similarly, if semantic orienting tasks eliminate age differences on the subsequent free recall test, it may be assumed that the usual observation of age differences in free recall performance following standard intentional learning instructions is due to inadequate or insufficiently deep semantic processing at acquisition.

Several investigators have examined age differences in free recall performance when semantic orienting tasks were compared with intentional learning instructions. Eysenck (1974) reported comparable age differences when the semantic tasks were producing an appropriate adjective or image, as did Erber, Herman, and Botwinick (1980) with a semantic task involving pleasantness judgments of word meanings. Perlmutter (1978) found similar results when comparing intentional recall with recall of words used in a word association task. Zelinski, Walsh, and Thompson (1978) also reported approximately equivalent age differences when comparing recall following intentional learning and pleasantness judgments. Thus, imposing semantic processing tasks on older subjects does not eliminate

or even attenuate age differences in recall. According to the logic described above, these findings indicate that older adults do not have a deficiency in semantic processing, but rather have problems at recall with memory search and retrieval. Nevertheless, Burke and Light (1981) commented, in their comprehensive review of the role of retrieval processes in age differences in memory performance, on the emptiness of the processing deficiency explanation of age-related memory problems. It had been assumed that providing semantic orienting tasks for older subjects promotes optimal encoding in contrast to instructions to simply "learn the words". However, the difference between young and old subjects given semantic orienting tasks is of the same magnitude as the age difference following intentional learning instructions, when tested by free recall. If the age difference following incidental instructions is attributed to retrieval difficulties, then the age differences following intentional instructions must perforce also be attributed to retrieval difficulties, the same conclusion arrived at by Schonfield and Robertson in 1966. The levels of processing approach has not elucidated the memory problems of older adults using these comparisons; in fact one might conclude from these studies that older adults have no problems at all with encoding, and only efficient retrieval is difficult.

Given these results, it has then been assumed that if acquisition is equated by imposing semantic orienting tasks, and memory search and retrieval requirements are reduced by providing retrieval support with a recognition test, age differences should be eliminated. In contrast to the free recall results, the recognition results are somewhat less consistent. White (cited in Craik, 1977) found that category judgments eliminated age differences in recognition, while following intentional learning, age differences remained. Perlmutter (1978) also reported significant age differences in recognition following intentional learning but not following the word association task. Mason (1979) reported no age differences in d' (a measure of sensitivity) following category judgments, although her young subjects outperformed her older subjects. Finally, Erber, Herman, and Botwinick (1980) reported that intentional instructions produced better recognition than pleasantness judgments for both young and elderly subjects. Some portion of the inconsistency observed may be due to the nature of the semantic orienting tasks utilized. This issue has not been addressed by a task analysis which might serve to clarify possible age differences in processing operations at acquisition. In addition, the inconsistency of the recognition results provides only weak support for the proposition that the memory

problems of older adults can be reduced by imposing semantic orienting tasks and providing recognition tests rather than free recall tests. Finally, given the theoretical confusion regarding precisely what processes are involved in recognition (Burke & Light, 1981), the finding of age differences in recognition following either intentional learning or incidental orienting tasks cannot be unambiguously attributed to either acquisition or retrieval deficits.

Recognizing the problems associated with clarifying the nature of memory deficits of older adults within the levels of processing approach, Craik and Simon (1980) recently proposed that older adults are handicapped by their reduction of processing resources, which prevents them from processing incoming stimuli to a "deep" or semantic level. In other words, semantic processing requires more attention than shallow processing. A related notion is that effortful processing, such as that required by rehearsal or memory search, depends upon an optimal amount of cognitive capacity, which is reduced with age (Hasher & Zacks, 1979). Burke and Light (1981) proposed that not only is attentional or effortful processing reduced in old age, but automatic processing is as well, and concluded that this reduction is attributable to reduced cognitive capacity. The common idea behind these suggestions is that memory tasks require much

cognitive "energy", which is reduced with increasing age. This orientation may provide a more fruitful direction for investigations of the specific mechanisms involved in age differences in memory performance. The attentional literature is reviewed next.

Attention and Vigilance

Theoretical Considerations: Attention

Attention has a long history in psychology. William James (1890) considered it to be "the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, consciousness are of its essence" (p. 403). He thought that people cannot attend to more than one event unless well-practiced, and cited people trying to carry out two tasks simultaneously. Attention is either passive and involuntary, or active and voluntary; attention facilitates memory and shortens reaction time. These themes dominate current theories of attention. Pillsbury (1908) reiterated these ideas, adding that attention affects memory both at the time of encoding and at recall. He further proposed that the frontal lobes are the locus of attention in the brain.

The topic of attention was lost to psychologists during the domination of the Behaviorists and Gestaltists, who spurned the mentalism implicit in any

consideration of cognition for half a century. A rebirth of interest in attention followed Broadbent's 1958 publication of Perception and Communication. His filter theory proposed that selective attention acts like a filter, blocking out unwanted inputs and preferentially allowing the desired input access to further processing. This selection is based upon physical characteristics rather than meaning. For example, in a dichotic listening experiment, the two messages are discriminated by spatial location, or by pitch. This theory accounted adequately for the early results of shadowing and split span studies, but further experimentation showed that under certain circumstances, meaning from the unattended message was noticed by the subjects. Also, attention can switch from channel to channel to follow the meaning of a message which alternates between channels. Triesman (1960) showed that, if a message arriving at the right ear, which is to be shadowed, switches to the left ear, while the unshadowed message switches to the right ear, subjects continue to shadow the original message even though they have been instructed to shadow the right ear only. This requires some analysis of meaning at the unattended ear, suggesting that an explanation of attention based entirely upon physical characteristics is inadequate.

Subsequently, Triesman (1964) proposed that the filter acts more like an attenuator, never completely blocking information but selecting on the basis of meaning. Deutsch and Deutsch (1963) and Norman (1968) further liberalized the filter idea by proposing that all inputs are analyzed fully, but only those that are relevant in a given context have access to conscious attention; in this approach the "filter" lies long after stimulus input rather than early, as in the Broadbent theory. This movable filter prompted others to conceptualize attention in terms of processes rather than bottlenecks.

Neisser (1967) distinguished between preattentive and attentive processes. Preattentive processes monitor all inputs for important information, such as a designated target, or one's name. Focused attentive processing is constructive; i.e., activated inputs are synthesized to form a percept that is recognized, and is experienced as conscious. This distinction is similar to recent discussions of automatic and conscious (Posner & Snyder, 1975), automatic and controlled (Schneider & Shiffrin, 1977), or automatic and effortful (Hasher & Zacks, 1979) processes. This theoretical approach was first clearly enunciated by Kahneman (1973), whose capacity model of attention stated that there is a limit on the amount of attention that can be allocated to different mental operations,

which differ in the amount of capacity they require. Furthermore, Kahneman suggested that, within the limits placed by the nervous system on stimulus processing, the capacity (or effort) available to task performance varies with the individual's state of arousal; response availability is a direct function of one's present level of physiological arousal. Navon and Gopher (1979) elaborated on this idea by stating that at any given point in time the human system has a limited amount of processing facilities, referred to variously as resources, effort, capacity, or attention; performance on a given task is positively related to the amount of resources available. Certain operations, such as sensory analysis, are automatic and require little or no attention, while others, such as rehearsal, require much attention and thus are referred to as effortful. Although a dichotomy is often implied in discussions of automatic and effortful processing, Hasher and Zacks (1979) pointed out that mental processes fall on a continuum from completely automatic to those requiring much effort.

Several characteristics distinguish automatic and effortful processes. Automatic processes do not require awareness or intention, and require little if any capacity. Once a process becomes automatic, it cannot be improved by additional practice (learning to read in early childhood is a good example). Automatic

processes do not interfere with other ongoing processes (Posner,1978). Effortful processes, in contrast, require intention, use attentional capacity, and can benefit from practice or feedback. They also interfere with other ongoing processes, as in a dual task experimental paradigm; in fact, attention or effort has been defined by whether and the degree to which interference occurs between two tasks or operations performed simultaneously (Keele, 1973). It has been suggested that the elderly have reduced processing resources, and this reduction accounts for the observation of age-related deficits on various cognitive tasks, including memory; these tasks require effortful processing, and a reduction of resources below some minimal threshold prevents their optimal performance (Hasher & Zacks, 1979).

Another theoretical approach to attention draws the distinction between "data-driven" (or bottom-up) and "conceptually-driven" (or top-down) processing (Norman & Bobrow, 1975). A bottom-up process operates only on the information coming from the periphery; e.g., identification of the lines and angles in the letter "A" facilitates their synthesis into the higher order form known as "A". A top-down process, in contrast, utilizes information stored in memory about the context to facilitate identification of a stimulus. For example, the identification of the blurred vowel in

the word "cat" might be facilitated if one knows from the context that a cat is being described. This distinction has been applied to studies of pattern recognition (Klatzky, 1980), peripheral encoding (Miller, 1979), and visual information processing (Kinchla & Wolfe, 1979). Recently, it has been suggested (Hoyer & Plude, 1980; Labouvie-Vief & Schell, 1982) that this distinction might prove useful in studies of age differences in attention (Madden, 1984; Rabbitt, 1979).

Theoretical Considerations: Vigilance

Vigilance was a very popular research topic following World War II, when investigators became concerned with optimizing detections by human watchkeepers scanning radar and sonar devices. Interest in vigilance has abated since the 1960's. Several theories of vigilance were current at that time, and arguments as to the correct theory dominated the literature. The most widely used vigilance task for several years was the clock test (Mackworth, 1961). Subjects were instructed to count the double clicks of a clock minute hand, of which there might be as few as a dozen during a two hour session. The task was fatiguing, and performance deteriorated after the first 10 or 15 minutes. The theories attempted to explain why performance deteriorated.

Frankman and Adams (1962) proposed the activation hypothesis, also referred to as the sensory habituation theory. They suggested that stimulus variation of the ascending reticular activating system (ARAS) is necessary to maintain responsiveness, and in a lengthy task with low density targets, the ARAS cannot maintain an optimal level of responsiveness. McGrath (1963) offered a similar explanation: "constant, monotonous stimulus conditions will lead to a lowering of cortical arousal and thus to less efficient responding" (p. 6). Walter (1964) considered decreases in expectancy to be responsible for performance deterioration. Mackworth (1968) suggested that the response decrement is due to habituation to repetitive events, an explanation that is similar to Sokolov's (1963) description of the development of the neuronal model. These theories all attempt to explain performance on the lengthy clock test or on other similar tsks. Shorter tasks have been developed, however, for which theoretical explanations have not been offered.

Davies and Tune (1969) defined vigilance as the ability to sustain attention regardless of what stimuli are occurring. Vigilance tasks involve the detection of signals, which may occur with a high density as well as a low density. For example, the continuous performance test, which is also referred to as a cognitive vigilance task, consists of a series of

single letters or digits. The observer must detect a specified stimulus sequence, such as X followed by A, or three consecutive odd numbers. The task may be as short as five minutes, during which the observer must maintain continuous attention in order to perform optimally. Reaction time or number of designated targets detected can be used as the dependent measure (Davies & Tune, 1969). Vigilance is considered to be a central process; declines in detections are correlated with decreased evoked potential amplitudes. It would be expected that age differences would be observed in vigilance performance because of the neurological changes associated with aging. These issues will be discussed below.

Attention and Aging

The research literature on attention and aging is relatively disorganized, in comparison with the literature on memory and aging. Several review papers and one entire volume (New Directions in Memory and Aging, edited by Poon, Fozard, Cermak, Arenberg, & Thompson, 1980) have recently appeared surveying the memory and aging literature, yet not a single comprehensive review paper of attention and aging has appeared. Nor is the present review comprehensive; the enormous volume of the literature prevents complete coverage of the topic. Emphasis, then, will be placed upon reports appearing recently, and the papers

selected fit largely into the limited capacity -- automatic/effortful processing framework described above. This approach predicts that since effortful processing requires and uses attentional capacity, and as attentional capacity is thought to be reduced with increasing age, tasks requiring effortful processing should yield larger age differences than tasks requiring automatic processing.

It should be emphasized that, in a manner analagous to that noted in the discussion of levels of processing, the reasoning underlying the distinction between automatic and effortful processing may be described as somewhat circular and post hoc. If a cognitive task, thought to be effortful, is given to young and elderly adults and age differences are noted, one is confirmed in the notion that it is an effortful process. However, should age differences fail to appear, one must then reassess the justification for deeming it to be effortful and consider perhaps that it is closer to the automatic end of the continuum. Conversely, if a task considered to be automatic shows significant age differences, it must then be considered to be effortful, at least for the older subjects. The only independent means of assessing the automatic/effortful distinction for a given task is to determine the effects of an intentional manipulation or to include the task in a dual task experiment. In both

situations no impact should be detected for an automatic process, while for an effortful process intention should raise and combination with another task should lower the performance level. As will be seen below, these independent validating tests are not often applied, thus raising the possibility that conclusions about age differences (or lack thereof) may be premature.

According to Hasher and Zacks (1979), frequency detection satisfies the functional characteristics for considering it to be an automatic task. In their second experiment, young and elderly adults were tested with a lengthy word list in which critical items occurred 0, 1, 2, 3, or 4 times. Half of the subjects in each group were informed about the subsequent frequency test, while the other half expected a subsequent memory test. For both young and elderly subjects, there were no differences between the informed and uninformed groups in judged frequency; by inference, frequency information is picked up automatically. However, while frequency judgments increased as actual frequency increased, it did so at a significantly slower rate for the elderly subjects than for the young subjects. This age difference was small, and might be due to the speeded nature of the task or to a conservative response bias on the part of the older subjects.

Memory for sex of voice might also be considered an automatic process. Kausler and Puckett (1981) tested young and elderly subjects under both intentional and incidental learning conditions. Voice recall was better for young than older subjects; for the young subjects performance exceeded chance in both conditions, while for the older subjects performance exceeded chance only in the intentional condition. These results suggest that sex of voice information is not picked up automatically by older adults, and thus may be for them an effortful process.

Mergler, Dusek, and Hoyer (1977) tested young and elderly adults for intentional recall of order information and incidental recall of the locations of superfluous pictures placed on each stimulus card. Significant age differences were found for both intentional and incidental recall. The lack of an age by condition interaction was interpreted as evidence that older subjects do not experience an attentional focusing deficit. Within the present context it might also be considered evidence that older adults pick up context information automatically; their lower incidental recall scores suggest that they do so less completely than young adults.

Schneider and Shiffrin (1977) developed a hybrid memory search/visual search task for demonstrating the distinction between automatic and controlled

processing. Plude and Hoyer (1981) used a card-sorting variant of this task to examine age differences in these processes. Young and elderly subjects performed the task under consistent mapping (i.e., automatic processing) or varied mapping (i.e., controlled processing) conditions. Age differences were found for the latter but not the former condition. Using a similar task, Madden and Nebes (1980) investigated the acquisition of automaticity by young and elderly adults. Although the task was somewhat simplified to prevent fatiguing the older subjects, it was found that the slope for the set size functions decreased at the same rate for both groups. Asymptotes were not reached, however.

Although there are inconsistencies in these results, it appears that, across a variety of tasks, age differences tend to be either reduced or eliminated when processing is relatively automatic. The findings of Madden and Nebes (1980), in particular, suggest that task familiarity and/or practice may be important for reducing age differences on certain types of cognitive tasks.

Age differences in effortful processing have been investigated in greater depth. A classical example of a task requiring effortful processing is the Stroop (1935) color-word test. Three cards are presented to the subject. Card A consists of the names of colors

(red, blue, green) printed in black ink, and the subject is asked to read the color names as quickly as possible. Card B consists of color patches, and the subject is asked to name the colors as quickly as possible. Card C consists of color names printed in contrasting colored ink, e.g., RED is printed in blue ink. Subjects are asked to name the color of the ink as quickly as possible. Card C elicits a great amount of interference from trying not to read the word, slowing performance considerably. The Stroop effect is usually attributed to the automatic activation of the color names on the third card (Warren, 1972). Conversely, naming the ink color satisfies the functional criteria for considering it to be an effortful task: it requires intention, awareness, and effort, and is interfered with by other cognitive operations. A handful of studies have compared young and older adults on the Stroop task, and are unanimous in agreeing that, although all subjects have particular difficulty disregarding the color name while naming the color of the ink, older subjects are disproportionately handicapped (e.g., Bettner, Jarvik, & Blum, 1971; Comalli, Wapner, & Werner, 1962; Willis, Cornelius, Blow, & Baltes, Note 1). Thus, older subjects have trouble focusing on relevant features of this task while ignoring irrelevant features to a greater degree than young subjects.

Several other tasks have been used to demonstrate older subjects' difficulties with effortful processing. Horn, Donaldson, and Engstrom (1981), in investigating the correlates of the decline in fluid intelligence with age, found that although measures of primary and secondary memory showed little relationship with age differences in fluid intelligence, measures of attention (backwards digit span, perceptual speed, and divided attention) did account for a substantial proportion of observed age differences in fluid intelligence. They considered the possibility that their results reflected losses of processing capacity with age. Given the assumption that fluid intelligence is tied to the integrity of the CNS (e.g., Horn & McArdle, 1980), this interpretation is in complete accord with the development of the present model (Horn, 1978, 1982).

In a factor analytic study of information processing measures among healthy men, Robertson-Tchabo and Arenberg (1976) identified an attention factor whose highest loadings were dichotic listening (-.71), simple reaction time (.54), and delayed recognition (-.51). This factor also had the highest correlation with age ($r = -.40$), and was assumed to reflect alertness to task demands.

Hoyer and Plude (1980) pointed out the necessity of distinguishing between selective-filtering and

selective-search tasks in consideration of age differences in attention. In a selective-filtering task, the designated target appears in a constant location, and irrelevant nontargets are to be ignored. Wright and Elias (1979) presented a centrally located target letter alone, and embedded in either neutral letters, the same letters, or letters keyed to an opposite response. Older subjects had longer reaction times to all conditions, but were not differentially slowed by noise effects (the neutral condition) or by response competition (same vs opposite distractors). Farkas and Hoyer (1980) reported similar effects. In a card sorting task in which the position of the target remained constant, and the irrelevant distractors appeared in similar or contrasting orientation relative to the target, none of the subjects were slowed disproportionately by the presence of contrasting irrelevant information. However, the oldest subjects were slowed by the presence of similar orientation distractors.

Selective-search tasks require the subject to find the target against a background of irrelevant stimuli; i.e., the position of the target varies from trial to trial. Rabbitt (1965) used a card sorting task with varying numbers of irrelevant nontargets. Subjects were to discriminate targets from one, two, four, or eight distractors. The older subjects were

disproportionately slowed as the number of nontargets increased. Farkas and Hoyer (1980) also reported an experiment in which the position of the target was varied. Only the oldest subjects were slowed by the presence of contrasting orientation distractors, while all subjects were slowed by the presence of similar orientation distractors. Overall, these results suggest that searching for a designated target is more effortful than simply ignoring irrelevant stimuli. Thus, older subjects appear to be particularly handicapped by tasks requiring effortful processing.

Wright (1981) compared young and elderly adults using a dual task paradigm in which the processing requirements of each task were varied independently. The digit span task used 2, 3, 5, or 6 digits. The reasoning task consisted of deciding whether a sentence of the type "A precedes B - AB" is true or false, and included active positive, passive positive, active negative, and passive negative problems. The digit string was presented, then the reasoning problem and response, then digit recall was asked for. Each digit string length occurred with each level of reasoning difficulty. Increasing age differences were found across increasing levels of difficulty. "With the highest memory load and most complex reasoning problems, not only are the older adults recalling only one-third of the digits, but they are also making

reasoning decisions at chance level" (p. 610). In a second experiment only a single task was given. Subjects were required to perform mental addition with varying memory load, from none (the entire problem presented visually and auditorially) to complete (auditory only). Age differences increased with increasing memory load. It was concluded that older adults have less processing capacity to allocate among mental operations than young adults.

In conclusion, it appears that across a wide variety of tasks, age differences are small or eliminated when automatic processing is required. However, when effortful processing is necessary for task performance, age differences are found to be an increasing function of the amount of effort or processing capacity (or attention) required. Attentional deficits have been proposed to account for age differences in both memory (Craik & Simon, 1980) and fluid intelligence (Horn, Donaldson, & Engstrom, 1981). The effortful-automatic distinction is clearly of both theoretical and empirical significance for investigations of cognitive aging. The studies reviewing age differences in vigilance are reviewed next.

Vigilance and Aging

Little attention has been given to age differences in vigilance performance in the past decade, most investigations having been conducted during the 1960's. Two reviews (Davies & Griew, 1965; Davies & Tune, 1969) concluded that there were few (if any) age differences in vigilance performance. For example, Griew and Davies (1962) compared young and elderly subjects on a continuous performance task requiring the detection of three consecutive odd numbers. Small age differences were observed when the dependent measure was recording the digits on paper, but performance was equivalent when subjects checked the numbers detected on a list or pressed a key to indicate their detections. Davies and Griew (1965) concluded that the failure to find age differences in vigilance performance was attributable to several possible reasons. Old subjects are more motivated than young subjects; age differences will not become apparent until the older subjects show EEG slowing; the old subjects were not old enough. In fact, the "old" subjects tested were primarily in their 50's. In contrast, Thompson, Opton, and Cohen (1963), using a similar continuous performance test, found age differences after five minutes; the subjects tested were in their 60'a and 70's.

Panek, Barrett, Sterns, and Alexander (1977), in their review of the vigilance and aging literature, concluded that age differences are small when preparation is possible and when the targets are well separated. They also considered the relationship between cautiousness and vigilance, citing Rees and Botwinick's (1971) finding that there were no age differences in detections, although older subjects had a higher criterion. They concluded that "older subjects appear to show greater caution than younger persons in monitoring and in their tendency to inspect signals for a longer time before responding" (p. 432). It should also be noted that most of the older subjects used in the studies reviewed were relatively young, and often still employed, suggesting further that job-related experiences may offset age-related decrements on such tasks.

Finally, a distinction should be made between lengthy vigilance tasks with low density signals, as in the clock test, and shorter tasks with higher density signals, as in the continuous performance test. It would be expected that age differences would be more pronounced on the latter type of task. Many ability and information processing tasks require continuous monitoring of incoming stimuli. The continuous performance test, and reaction time tasks with varying preparatory intervals (e.g., Botwinick & Thompson,

1966), require continuous attention, or vigilance, in order for optimal performance to be achieved. Age differences are noted on such tasks if the signals are presented relatively rapidly (e.g., 1 per second) and if the subjects are older than those typically used in the studies reported during the 1960's.

The next stage in the sequence of developing the proposed model is to attempt to specify the underlying mechanisms responsible for attentional problems among the elderly.

Evoked Potentials and Aging

The evoked potential (EP) or event-related potential (ERP) is obtained by computer averaging of brain waves that are time-locked to some specifiable event. The waveform which results consists of a series of negative and positive deflections which are referred to as components. These components may be classified into three categories on the basis of time from the eliciting stimulus and the contribution of cognitive processes. The earliest components, within 50 msec of stimulus onset, are determined by the physical characteristics of the stimulus, are unaffected by cognitive processes, and are useful for assessing neurological disorders in the sensory pathways. The middle components, 50 to 150 msec poststimulus, are stimulus-evoked waves which also vary in shape as a function of certain psychological variables. The later

components are also referred to as endogenous because their shape is determined by cognitive operations rather than by characteristics of the eliciting stimulus.

Research during the past decade has examined cognitive and neurological correlates of the various components, and recently the feasibility of using certain EP components in the evaluation of cognitive aging and neurological decline has also been investigated (Squires, Chippendale, Wrege, Goodin, & Starr, 1980). This section reviews research findings on age differences in each of the three categories of components, with the aim of tentatively identifying underlying mechanisms which account for age differences in attention. Latency, amplitude, and scalp topography differences are considered. The present discussion is included for purposes of developing the logical and theoretical rationale necessary for developing the proposed model.

Early Components

The earliest potentials which have been investigated in aging subjects are the brainstem auditory evoked potentials (BAEP). They are of very short latency, and are thought to reflect the responses of specific neural generators in the brain stem. Seven peaks have been identified within 10 msec of stimulus onset, representing the acoustic nerve (I), the

cochlear nucleii (II), the superior olivary complex (III), the lateral lemniscus (IV), the inferior colliculus (V), possibly the medial geniculate (VI), and possibly the auditory radiations (VII) (Starr & Hamilton, 1976).

Michaelewski, Patterson, Thompson, Bowman, and Litzelman (cited in Smith, Thompson, & Michaelewski, 1980) investigated age differences in the BAEP. The older subjects had longer latencies for waves I, II, III, and IV than either middle-aged or younger subjects. The later waves were also of longer latency for the older subjects, but nonsignificantly so. Patterson, Michaelewski, Thompson, Bowman, and Litzelman (1981) found that older subjects had longer wave III latencies at all intensities (60 - 80 dB), and longer waves I, II, and IV latencies at 60 dB only. Also, women in all three age groups showed shorter wave IV and wave V latencies than the male subjects. Beagley and Sheldrake (1978) found no significant age-related latency differences, although they reported that the amplitude of wave V tended to decrease with increasing age. Harkins and Lenhardt (1980) found that elderly subjects had longer wave V latencies than young subjects at all intensities utilized (45 - 80 dB), significantly so below 70 dB. They also reported reduced amplitude for wave V, and concluded that this reduction is due to cellular atrophy in the brain stem.

Inconsistencies across studies may be a function of the varying stimulus parameters included for investigation (Street, Perry, & Cunningham, 1976).

Middle Components

One or more of the components falling 50 to 150 msec poststimulus have been reported to be of longer latency for elderly adults than for young adults in the visual and somatosensory modalities (Smith, Thompson, & Michaelewski, 1980). Latency age differences have not been reliably reported for the auditory modality (Ford, Hink, Hopkins, Roth, Pfefferbaum, & Koppell, 1979). Amplitude age differences have been reported across all three modalities. For example, Ford and Pfefferbaum (1980) reported that older subjects showed larger P1 and smaller N1 components than young subjects, particularly at frontal electrode placements, following passive auditory stimulation. They concluded that "the diminished negativity over the frontal area of the brain" was due to cellular atrophy, particularly loss of dendritic mass (p. 118). In contrast, when elderly subjects are actively attending to stimuli in order to perform a designated task, there are no significant age differences in N1 amplitude for either visual (Ford, Roth, Mohs, Hopkins, & Koppell, 1979), or auditory (Ford, Hink, Hopkins, Roth, Pfefferbaum, & Koppell, 1979), modalities.

Hillyard and Woods (1979) provide evidence that the N1 component is differentially enhanced when attention is directed to an input channel, in comparison to passive processing. They noted that "the interchannel distribution of N1 may index the allocation of limited attentional resources to the appropriate channel to achieve optimal performance" (p. 359). The failure to find age differences in the amplitude of N1 in a selective attention task has been interpreted as evidence that older adults can attend selectively as efficiently as young adults. However, this conclusion must be qualified by noting that the older subjects tested in these studies were carefully screened to exclude any subjects with sensory, cognitive, or health problems; those tested were extraordinarily superior to elderly adults in general. It is likely that a more representative sample of elderly adults would show N1 amplitude and latency age differences; however, it is unlikely that such subjects could be successfully tested in such a demanding task.

Late Components

The components falling after 150 to 200 msec poststimulus are of two types. The P2, N2, and P3 components are distinct waveforms that appear when the subject is asked to perform a task using the stimuli to which he is exposed. For example, if subjects are

asked to detect and count tones which are slightly louder than a string of background tones, the targets will elicit a larger P3 than the nontargets. The second type of late component is the contingent negative variation (CNV), one of several slow waves that can be observed in an averaged waveform. If two stimuli are paired, such that the first acts as a warning signal for the second, imperative stimulus, a sustained negative slow potential appears in the S1 - S2 interval. These two sorts of components may occur in the same record.

Generally, all late components show significantly longer latencies in older subjects than in young subjects (Smith, Thompson, & Michaelewski, 1980), and with increasingly difficult tasks the age differences in latency increase accordingly. Brent, Smith, and Michaelewski (1977), and Goodin, Squires, Henderson, and Starr (1978) reported longer latency for N2. The latter investigators also noted that between 15 and 75 years of age P3 latency increases by 1.8 msec per year. It is usually concluded that the lengthening of latency with age of the later components is due to slowing of neural transmission, which is in turn attributed to cell loss and degeneration with age (Birren, Woods, & Williams, 1980). It has also been suggested that the slowing of these later components, which reflect cognitive processes, may be due to older subjects

taking longer to make a decision (Smith, Thompson, & Michaelewski, 1980). Both proposals may, of course, be considered jointly to account for the observed slowing.

Amplitude age differences are not consistently observed for the later components. Ford, Hink, Hopkins, Roth, Pfefferbaum, and Koppell (1979), using an auditory selective attention task, found no significant age differences in P3 amplitude for either the attended or unattended channels. Using similar procedures, Goodin, Squires, Henderson, and Starr (1978) reported that P3 amplitude decreased significantly between 15 and 75 years of age at the rate of .18 mV per year (by use of regression procedures). Brent, Smith, and Michaelewski (1977) found that P3 amplitude to unexpected and infrequently presented stimuli was smaller for older adults than for young adults. Michaelewski, Patterson, Bowman, Litzelman, and Thompson (1982) investigated age differences in the P3 component to missing auditory stimuli, and found that P3 amplitude was reduced in older subjects at Cz and Pz electrode placements, but not at Fz. Beck, Swanson, and Dustman (1980) examined the effects of age on visually evoked potentials across the adult life span, and reported no amplitude differences for N2 and P3. Such inconsistencies may be attributable to several sources. Sampling problems may account for failure to find age differences as

described above. Sensory modality differences may exist as a function of the stimulus parameters, independent of the effects of age. Task differences may also contribute to the differences between studies. Two varieties of P3 waves have been identified. Those occurring to unexpected, rare stimuli are largest over frontal and central cortex, and appear to be related to orienting (Courchesne, 1978). Those occurring to task-relevant stimuli are largest over central and parietal cortex, and appear to be related to decision-making processes (Squires, Squires, & Hillyard, 1975). If studies of age differences in P3 amplitude are divided according to these two paradigms, age differences are relatively consistent for frontal, orienting tasks, while they are less consistent for tasks tapping decision-making processes. A consideration of scalp topography differences will clarify this distinction.

Anterior-posterior differences in scalp topography have consistently differentiated young and older subjects (Smith, Thompson, & Michaelewski, 1980). For young subjects, EP amplitude is largest at central and parietal recording sites, while older subjects have a more equipotential distribution across the entire scalp. This difference has been attributed to selective cortical cell loss, specifically that of the frontal lobes. Ford and Pfefferbaum (1980) reported

that increases in the ratio of fluid to brain tissue in the frontal cortex, recorded using CT scans, are significantly correlated with longer P3 latency. A correlation that approached significance was that between more positive P3s at frontal locations and ventricular widening. Thus, structural changes in the aging brain may account for some of the observed age differences in ERPs. In this vein, Beck, Dustman, Blusewicz, and Cannon (1979) suggested that reduced P3 amplitude may be due to deterioration of large pyramidal apical dendrites. Further, the P3 amplitude reduction is then related to psychological or cognitive age differences because these apical dendrites may be the storage sites for central programs. Their loss beyond some critical threshold would reduce the elderly person's ability to cope efficiently with complex information processing.

CNV

The CNV has been considered to be an index of expectation (Walter, Cooper, Aldridge, McCallum, & Winter, 1964), of attention (Tecce, 1972), and of alertness (Posner, 1978). It was originally thought to be a unitary shift, because the S1 - S2 interval used was typically between one and two seconds. It has subsequently been discovered that, if the interstimulus interval is extended to five or ten seconds, two distinct components of the CNV are found (Weerts &

Lang, 1973). The early component follows the warning signal, is largest over frontal regions, and appears to reflect alerting or orienting to the warning signal. The later component precedes the imperative signal, is largest over sensorimotor cortex, and appears to reflect cortical motor preparatory processes (Hansch, Syndulko, Pirozzolo, Cohen, Tourtelotte, & Potvin, 1980). Alternatively, the early component is simply a negative afterwave to S1 while the later component is an instance of the readiness potential (Smith, Thompson, & Michaelewski, 1980).

When the S1 - S2 interval is short, and the CNV appears as a unitary wave, inconsistent age differences in the CNV amplitude have been reported. Ford, Roth, Mohs, Hopkins, and Koppell (1979) tested young and elderly subjects using the Sternberg (1969) memory scanning task. The interstimulus interval was one second. CNV amplitude decreased with increasing memory load, but there were no age differences observed. Michaelewski, Thompson, Smith, Patterson, Bowman, Litzelman, and Brent (1980), in a visual divided attention task, reported that frontal CNVs were reduced in the elderly subjects in all conditions, although no age differences were noted at central or parietal electrode placements. Marsh and Thompson (1973), using a pitch discrimination task, found that difficult discriminations produced longer RTs for both young and

elderly subjects; however, CNV amplitude was not related to RT, and no age differences in CNV amplitude were observed. In contrast, Harkins, Moss, Thompson, and Nowlin (1976) found that CNV amplitude was related to RT in a group of elderly men; however, no comparison group of young subjects was included, so that age differences were not assessed. Using longer S1 - S2 intervals, several investigators have reported few age differences in the early CNV component, but the later component is reduced or missing in older subjects (Loveless & Sanford, 1974; Schaie & Syndulko, 1978).

Two conclusions are possible. Regarding the reduced later, or preparatory component, among older subjects, Loveless and Sanford (1974) proposed that older subjects have problems initiating preparation at the appropriate time. Regarding the report of reduced frontal CNVs, Smith, Thompson, and Michaelewski (1980) suggested that selective frontal cortex cell loss is related to diminished performance capacity. Because of the lack of agreement about what the CNV represents and the inconsistencies among the results of the studies surveyed above, these suggestions are only tentative.

Summary

Throughout the present review of age differences in various evoked potential components, it has been suggested that cortical aging, particularly of the frontal lobes, is in part responsible for the age

differences reported. Hillyard, Picton, and Regan (1978), in a review of the relationship between attention and ERPs, have concluded that attentional deficits, indexed by age differences in ERPs, may be causally related to a variety of perceptual and cognitive deficits in the elderly. The following section reviews the structural changes of the CNS with increasing age which may account for certain of the cognitive and psychophysiological age differences considered above.

Neurophysiology and Aging

Introduction

Before discussing the evidence for CNS changes with age, it is appropriate to present the references regarding the localization of attention and vigilance in, respectively, the frontal cortex and the reticular activating system.

Evidence for the functions of the frontal cortex comes from primate research and from studying humans with frontal lesions. Monkeys with frontal lesions are unable to inhibit responses to irrelevant stimuli or to maintain goal-directed, programmed behavioral sequences. They have difficulties of concentration, are distractible and inattentive (Luria, 1973; Milner, 1970). Frontal humans, similarly, lack initiative, planning ability, or foresight. They show subtle changes in alertness and affect, are perseverative, and

show impairments on complex cognitive tasks (Damasio, 1979; Milner, 1970). It is generally thought that the frontal lobes are part of a system which is responsible for initiating and maintaining attention. This "frontal system" (Nauta, 1971) includes cortical and subcortical linkages with the limbic system, the reticular activating system, and also with sensory and motor cortex. The frontal lobe "judges and regulates ongoing external perception, and calculates appropriate responses to what is being perceived; it is primarily concerned with high-level cognition" (Damasio, 1979, pp. 370-371).

Vigilance has been localized in the rostral brainstem area of the reticular formation (Hernandez-Peon, 1964). Physiologically vigilance is defined as non-sleep, non-coma, a state of readiness for experience and thinking. The brainstem reticular activating formation is thus responsible for changes in the overall degree of alertness (Guyton, 1977), generalized and elementary forms of attention (Luria, 1973), and for alerting cortical centers to significant changes in the environment "that could necessitate adopting a different 'set'" (Milner, 1970, p. 291).

Age Changes in the CNS

There are several structural changes that are observed in normal, relatively disease-free individuals with advancing age. Brizzee, Ordy, Knox, and Jirge

(1980) have recently summarized the structural alterations of senescent individuals. Both brain weight and brain volume decrease with increasing age, while intercranial space approximately doubles. The sulci both widen and deepen, and there is an increase in the width and mass of the gyri. The number of synapses decreases. There is a generalized loss of dendrites in the cortex, while neurofibrillary tangles and amyloid and senile plaques increase, particularly in the frontal and temporal cortices and in the hippocampus. Finally, neuronal loss is noted in the cortex, cerebellum, anterior thalamic nucleii, striatum, putamen, hippocampus, substantia nigra, and the locus coeruleus.

Cortical neuronal loss is not random, however. Cellular atrophy and degeneration are most marked in the frontal, prefrontal, and superior temporal areas (Scheibel & Scheibel, 1975), perhaps accounting for the observed deficits among older individuals on attentional and complex problem-solving tasks. Furthermore, cell loss or degeneration of the thalamic reticular formation (Brody, 1973) and of the retinogeniculostriate system (Brizzee, Ordy, Knox, & Jirge, 1980) might be expected to account for older adults' problems in maintaining an adequate level of alertness or vigilance for efficient performance on various cognitive tasks.

A particularly vulnerable brain structure among older individuals is the locus coeruleus (LC), located in the medial brain stem, which loses 40% of its neurons with age (Kubanis & Zornetzer, 1981). This nucleus produces most of the brain's norepinephrine, and has connections to the cortex, thalamus, hippocampus, amygdala, brain stem, and hypothalamus. The multiple projections to thalamic and cortical areas "serve to maintain levels of excitability optimal for information processing of environmental stimuli relevant to coping" (Amaral & Sinnamon, 1977, p. 184). Norepinephrine release produces EEG arousal and behavioral alerting by lowering the threshold of reticular neurons in the brain stem, producing an alert, attentive state. The LC may be intimately involved with observed cognitive age deficits; not only vigilance but also memory and attention are implicated because of the prolific reciprocal projections with hippocampus and sensory and frontal cortex. In particular, norepinephrine is thought to be involved in the storage of recently acquired information (Hunter, Zornetzer, Jarvik, & McGaugh, 1977). Furthermore, with increasing age, the LC, hippocampus, and frontal lobes are increasingly susceptible to neuronal and dendritic loss, and thus it would be predicted that, with increasing age, even the

most disease-free aging individuals would evidence attention and memory problems.

CHAPTER III
THE PROPOSED MODEL

The preceding literature review has documented age differences in memory and in effortful attentional processing. It has been proposed that age-related attentional deficits are causally related to age differences in memory (Craik & Simon, 1980; Kinsbourne, 1980; Thompson, 1980). These suggestions regarding the causes of age differences combined with the empirical findings reviewed above provide a theoretical rationale for the proposed research. Ultimately, cognitive functioning is tied to the integrity of the central nervous system. Selective cell death in the ARAS and in the frontal cortex of aging individuals would be expected to underlie attentional deficits and therefore be causally prior to memory performance. These proposed relationships can be incorporated into a simple model which describes their causal interactions, as shown in Figure 3-1. According to this model, measures of vigilance and attention are correlated, and both constructs are causally related to memory performance; age differences in attention and vigilance account for some

significant proportion of age differences in memory, and are causally related to such age differences.

Linear structural equation modeling (Joreskog, 1979) provides a set of statistical procedures for determining whether data collected in a study are consistent with a hypothesized causal model. It is necessary to have an a priori rationale such as that described above as a basis for assigning the causal order of the variables (Kenny, 1979). Correlational inference in then possible; "inference means confirmation or disconfirmation of a scientific hypothesis by the use of the data" (Kenny, 1979, p. 1). Linear structural equation models with latent (unobserved, unmeasured) variables attempt to explain the statistical properties of the measured variables (indicators) in terms of the hypothesized latent constructs. This approach consists of two components: a measurement model and a structural model. The measurement model examines how well factors are measured by observed variables. The structural model then examines the relationships among the constructs of interest. The goal is to optimally estimate the parameters of the model and determine whether the model fits the data by a chi-square (χ^2) test of the goodness-of-fit (Bentler, 1980). If the model provides an unacceptable fit to the data, it can be rejected as a reasonable description of the causal structure

underlying the observed pattern of the data. If the proposed model cannot be statistically rejected, it is assumed to represent an acceptable description of the underlying causal structure. Ideally, alternative models can be compared statistically to determine which one provides the best fit to the data (Bentler & Speckart, 1979; Horn & McArdle, 1980). It is necessary that the alternative models be a subset of the initial model. The difference in χ^2 values between two models is itself a χ^2 statistic, which can be used to assess the significance of the parameters that differentiate the models (Bentler, 1980).

In the present case, a version of the simple model described above was tested to determine if it is a reasonable description of the causal relationships among the three constructs of interest in groups of different ages. The above model was expanded in the following manner. Indicators of socioeconomic status have been implicated in explaining cognitive test performance across the life span (e.g., Botwinick, 1977; Maruyama & McGarvey, 1980). Therefore, an SES construct was added to the model in order to determine its relationship to the constructs of interest. Secondly, because of both variation in chronological age within each age group and the intergroup differences in chronological age variability, a chronological age indicator was included in order to

determine the amount of variance in the performance data attributable to chronological age. The expanded simple model is shown in Figure 3-2.

The single-headed, straight arrows indicate the direction of the hypothesized causal influence, while the double-headed, curved arrow indicates that attention and vigilance may be associated without positing any causative influences determining their joint and independent effects, other than SES and chronological age. In the language of causal modeling, memory, attention, and vigilance are the endogenous latent constructs while SES and age are the exogenous latent constructs. Each of the unobserved endogenous constructs is represented by three indicator (task) variables, and each of the exogenous constructs is represented by a single indicator.

Ideally, a comparison of the dominance of bottom-up versus top-down attentional processing could be made by comparing the adequacy of the fit to the data of the model described above with a second model in which reciprocal causation is included between attention and memory, as is shown in Figure 3-3. The first model, with the single arrow only between attention and memory, assumes bottom-up processing only, in which stored memory routines are not activated in order to analyze incoming stimuli. The second model, with reciprocal causation, assumes that,

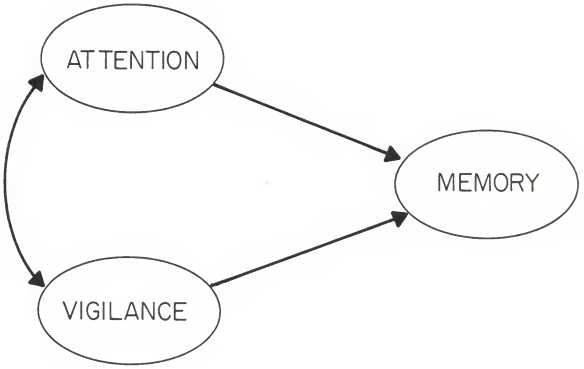

Figure 3-1

The Simple Model

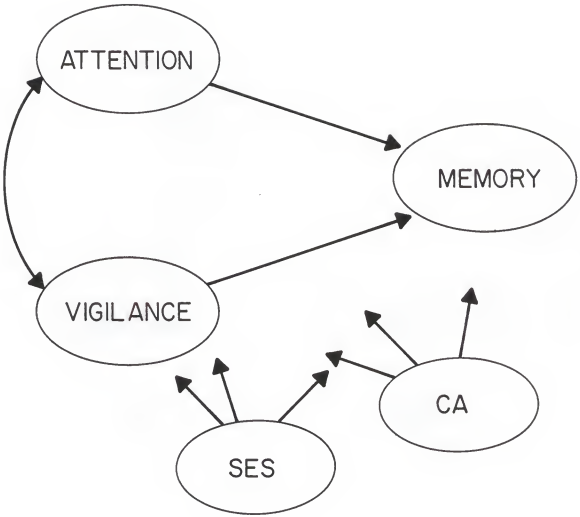

Figure 3-2

The Expanded Simple Model

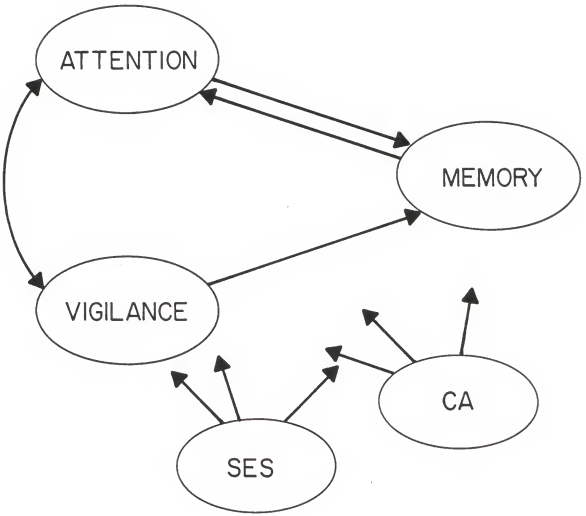

Figure 3-3

Reciprocal Causation Model

in addition to bottom-up processing, such stored routines can be activated to facilitate processing. Unfortunately, this alternative model is not identified; i.e., there is no unique solution possible for the set of linear equations when the additional parameter is added to the model. Therefore this particular model comparison cannot be made.

The logic of the proposed model requires that a simultaneous analysis be undertaken to determine whether the observed covariances among groups of subjects of different ages would be acceptably fit by the model. This procedure is analagous to the use of age-comparative factor analysis (e.g., Cunningham, 1980a), in which the simultaneous analysis yields a goodness-of-fit χ^2 test for the equality of factorial structure. The LISREL program (Joreskog & Sorbom, 1978) is used to determine whether the observed patterns of covariances among the indicator variables are consistent with the proposed model. LISREL provides a maximum likelihood solution, a χ^2 test of goodness-of-fit, and an associated probability (p) value to be used in determining the plausibility of the model being tested. The χ^2 statistic provides a test of the proposed model "against the general alternative that the measured variables are simply correlated to an arbitrary extent" (Bentler, 1980, p. 428). Large p values are considered to correspond to a good fit,

while small p values indicate a poor fit between the model and the data. For this study, the conservative .01 probability level was chosen as the criterion for accepting the simultaneous fit of the model.

The specific hypotheses are as follows. Given the typical neurological changes associated with advancing age, a group of older subjects should show higher correlations among indicator variables than a group of younger subjects, who would be presumed to be at their peak in terms of neurological integrity. However, younger-old subjects (up to about age 70) may not have experienced sufficient CNS cellular atrophy in the structures of interest to fall below some limiting threshold and show attentional deficits of a sufficient magnitude to impair memory performance. Birren's (1963) discontinuity hypothesis is relevant to this issue. He noted that "psychological functions are related to physiological variables when the latter lie in an abnormal range as in disease" (p. 289), or presumably when normal neuronal loss has accumulated past some limit. Elderly volunteers in cognitive research tend to be healthier and better educated than elderly adults in general; although they might be expected to show mean differences in performance in comparison to younger adults, they may fail to show qualitative or structural differences in performance. Therefore it is hypothesized that a simultaneous

analysis of the young and younger-old covariance matrices will not be rejected by a goodness-of-fit test. In contrast, older-old subjects (in their 70's and 80's) should be experiencing sufficient attentional decrements to produce memory impairment of such a magnitude that a simultaneous analysis of the younger-old and older-old covariance matrices would be rejected by a goodness-of-fit test.

It is appropriate to present the full model at this point. From the variance-covariance matrix of the indicator variables, each of the unknown parameters shown in Figure 3-4 can be estimated. The gammas (γs) are the structural coefficients linking the exogenous and endogenous constructs. The betas (βs) indicate the strength of the causal relationships among the endogenous constructs, and are the particular parameters of interest in the present age-comparative research. Thus, it is hypothesized that β1o and β2o are significantly greater than β1y and β2y, and β1oo and β2oo are significantly greater than β1yo and β2yo. The lambdas (λs) are the factor loadings (coefficients) of the indicators (I) regressed on the unobserved dimensions. The epsilons (εs) denote measurement errors associated with the observed indicators. The Psi (ψ) and Phi (ϕ) matrices represent the factor covariances for the endogenous and exogenous constructs, respectively.

It is necessary to fix at least one of the coefficients for each construct to some arbitrary number, usually unity, in order to have an identified model (Kenny, 1979). Education is the single indicator utilized to represent SES because of the large proportion of missing data for the income and occupation questions; both SES and chronological age, then, are assumed to be measured perfectly.

To summarize, the specific hypotheses are as follows:

1. A simultaneous analysis of the young and young-old covariance matrices will not be rejected by a χ^2 goodness-of-fit test.
2. A simultaneous analysis of the young-old and old-old covariance matrices will be rejected by a χ^2 goodness-of-fit test.
3. The betas for the old will be significantly larger than the betas for the young.
4. The betas for the old-old will be significantly larger than the betas for the young old.

The data analysis plan requires an initial simultaneous analysis of the young group and the entire old group. If the χ^2 goodness-of-fit statistic indicates an acceptable fit, further analyses beyond an examination of the betas will be unnecessary. If the χ^2test indicates an unacceptable fit, further analyses

of the young and young-old, and the young-old and the old-old, groups will be undertaken, as described above, in order to more precisely specify the nature of the structural differences observed and to assess age differences in the betas. These comparisons will specifically test the four hypotheses listed above.

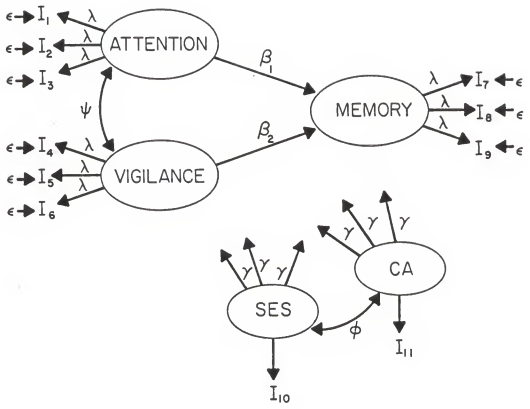

Figure 3-4

The Full Model

CHAPTER IV
METHODOLOGY

Subjects

The young subjects were 98 adolescents (age 14 to 19 years, X = 15.9) from Newberry Junior-Senior High School, of whom 51 were male and 47 were female. The older subjects were 140 community-dwelling adults (age 53 to 87, X = 69.5) from Gainesville, Brevard County, and Martin County, of whom 89 were female and 51 were male. The older subjects were recruited using a variety of procedures: an entire retired businessperson's group was tested in Merritt Island; subjects were recruited from a list of persons who had previously expressed interest in participating in research in Gainesville; persons living in two federally subsidized apartment complexes in Gainesville were contacted by telephone; additional persons responded to an advertisement in an Older Americans Council newsletter; further recruitment was conducted through personal contacts. The high school age subjects were included in order to increase the variability of the young group. Typically, in age comparative research, the use of homogeneous college students as the young comparison group results in

restriction of range (Nunnally, 1978). For the older subjects, subjective health status was ascertained by a brief questionnaire regarding recent illnesses, chronic diseases, medication usage, and a health rating based on a four point scale (excellent, good, fair, poor). Of the 114 older subjects who completed the rating scale, 100 (87.7%) reported themselves to be in good or excellent health. All subjects were given a brief socioeconomic questionnaire. Adolescents were asked to report their parents' approximate income, education, and occupations, while the older adults were asked comparable questions about themselves, prior to retirement for those retired. Initial pilot testing with younger adolescents indicated that they had only very general concepts of their parents' education and income. Therefore, education was assessed on a six point scale ranging from grade school to post-graduate degree for both groups in order to maintain comparability. The adolescents reported their parents to have attained, as an average, high school and some college education; only 24 (24%) reported college and post-graduate degrees. The older subjects reported similar educational attainment, with 36 (16%) reporting college and post-graduate degrees.

Procedure

The young subjects were tested in intact classes in the school; an English class from each grade (9 through 12) was selected for this purpose. The number of students per class ranged from 16 to 36. The older subjects were tested in several different settings. Ten percent were tested individually. The remainder were tested in groups ranging in size from two to forty, with most of the groups consisting of from four to ten subjects. For both age groups, the larger group sizes resulted in the loss of data because of inattention, acoustical and lighting problems, and cheating. Data from nine young and eighteen older subjects were discarded for these reasons. Subjects were given complete information about the nature and purpose of the study prior to testing in full accordance with University Human Subjects Committee guidelines.

The informed consent forms (see Appendix A), tests, and questionnaires were compiled in folders for each subject to facilitate administration. All formal data collection was conducted by the author. Testing required approximately one hour per session. The order of the tasks was as follows: memory span, ADEPT word recognition, Identical Pictures, free recall, proofreading, Stroop color-word, paired-associate recall, continuous concentration, and letter matching.

Tasks

The tests that were selected for inclusion were chosen for brevity and for ease of administration in a group setting. Operationally, the distinction between attention and vigilance tasks was based on whether the targets are clearly defined, predictable, and of high or of low density. In the attention tasks, e.g., Identical Pictures, each item contains a clearly defined target (the item to be matched). In the vigilance tasks, the targets are not clearly defined, appear irregularly, and have a low density; thus, in word recognition, 20% of the items were targets (words) and 80% of the items were nonwords. The proofreading task was constructed in a parallel manner: 10% of the items were targets (misspelled words), and 90% were correctly spelled words. Finally, it was considered important that one task per construct consisted of nonverbal items (paired associates, Identical Pictures, and continuous concentration). Thus the results could be generalized beyond verbal processing to other kinds of tasks.

Memory

Free recall, paired associate recall, and memory span were tested. For the free recall test, 18 unrelated words were printed in large type in two 9-word columns on a single sheet. The words were selected to be of medium frequency (between 30 and 60

per million, Thorndike & Lorge, 1944), and each began with a different letter. Subjects were given two minutes to study the words, and were then asked to turn the page and write on the next blank page all of the words that they could remember in any order. Four minutes were allowed for recall. The paired-associate test, MA-1 (Ekstrom, French, & Harmon, 1976), consists of pictures of common objects, each paired with a two digit number. During the study phase, subjects studied the picture-number pairs for four minutes. During the 3-minute test phase, the pictures are presented in a different order, and subjects were to write the appropriate number next to each. The memory span test, MS-3 (Ekstrom, French, & Harmon, 1976), consists of sequences of letters from three to ten letters long, each of which is presented auditorially at the rate of one letter per second. After each sequence is presented, subjects wrote the sequence in the same order that it was presented. Free recall and paired-associates included a brief practice phase to ensure that all subjects understood the instructions. Dependent measures in each case were number correct.

Attention

The Stroop color-word test, described in Chapter 2, has been adapted for group administration by Willis, Cornelius, Blow, and Baltes (Note 1). In this version, parts 1 and 3 consist of color patches, for which

subjects write the first letter of the name of the color. In parts 2 and 4, color names are printed in competing colors, and subjects write the first letter of the name of the ink color. Subjects were given thirty seconds for each part, and the dependent measure was the sum of the standardized scores for the color and name sections. The second task was a paper and pencil version of Posner's (1978) letter-matching task, developed by Lansman (Note 2). The task involves determining whether two letters are the same or different under two conditions. In the first condition, letters were judged to be the same if they were physically identical, e.g., AA. In the second condition they were judged to be the same if they have the same name, e.g., aA. Each part takes one minute, and the dependent measure was the sum of the number correct in the two sections. The third task was a perceptual speed task, Identical Pictures, P-3 (Ekstrom, French, & Harmon, 1976), in which the subject checked one of five line drawings as being identical to a standard. Subjects were given 1 1/2 minutes for each of the two sections. The dependent measure was the total number correct. Each of these tasks included a brief practice section.

Vigilance

The ADEPT word recognition test and the continuous concentration test are pencil and paper vigilance tasks

developed by Willis, Cornelius, Blow, and Baltes (Note 1). The former consists of lengthy lists of three-letter (CVC) syllables, and subjects circled any which were English words during a three minute period. The dependent measure was the number correct. The continuous concentration test consists of simple arithmetic problems. In the first section subjects first computed the sums for two problems (10 + 4 - 6 = ?; 7 - 2 + 8 = ?), and then computed the sums of the two sums. In the second part the difference between the two sums was computed. Subjects were given two minutes for each section. The dependent measure was the sum of the number correct in the two sections. The third task was a proofreading task. Subjects were given a one and one half page passage of simple text (8th grade reading level) and instructed to circle all misspelled words during a three minute period. The dependent number was the number correct. Brief practice phases were included in each task.

CHAPTER V
DATA ANALYSES AND RESULTS

Mean Age Differences: Descriptive Results

The resulting means, standard deviations, and reliabilities for the young and old groups are presented in Table 5-1. In contrast to the typical findings in age comparative research using cognitive variables, the variable covariances were not increased in the old as compared to the young, probably due to the inclusion of the heterogeneous adolescent group. Separate analyses of variance, shown in Table 5-2, were undertaken to assess age differences in mean level of performance for each task. The older subjects outperformed the young subjects on the proofreading task; this task appears to assess verbal ability as well as sustained concentration, so it is unsurprising that the older subjects performed better than the adolescents. No statistically significant age differences were found for word recognition, continuous concentration, and memory span, although there was a small differences favoring young subjects on the span test, a result which is consistent with the cognitive aging literature (cf Craik, 1977). The lack of age differences in the other two tasks probably reflects

the young subjects' greater speediness being offset by the older subjects' greater familiarity (via years of practice) with the content, i.e., words and simple arithmetic. Thus, an appropriately designed study would no doubt identify the word recognition and continuous performance tasks as assessing aspects of crystallized intelligence (Horn, 1982).

Age differences favoring the young subjects were found for the remaining tasks. Young subjects virtually always outperform older subjects on free recall and paired-associate tasks. For the attention tasks, the combination of time constraints and the unfamiliarity of the tasks was detrimental to performance for the older subjects. In addition, the age differences suggest that older subjects have impaired attentional mechanisms; e.g., young subjects showed a 31% slowing in the Stroop name condition while the older subjects showed a 49% slowing, indicating greater difficulty in avoiding the distracting influence of the color name. However, mean age differences or the lack of mean age differences are not evidence for similarities or differences in causal processes.

Simultaneous Comparison of Young and Old

Uniformly scaled variance-covariance matrices (see Appendix B) for the young and old subjects were computed using the COFAMM program (Sorbom & Joreskog,

1976). A simultaneous comparison of the most strict model, shown in Figure 5-1, was carried out using LISREL IV (Joreskog & Sorbom, 1978). All parameters were constrained to be equivalent across age groups, with the following exceptions: factor variances in the endogenous factor covariance matrix (Psi) for the young group were fixed at unities, and the measurement errors were allowed to vary between groups. One lambda for each of the endogenous constructs was fixed at unity in order to resolve the identification problem. This model yielded a χ^2 of 461.197 with 114 degrees of freedom ($p = 0.0$), indicating a very poor fit of the model to the data. Subsequent models, each of which was nested in the preceding model and represented a progressive relaxation of the parameter constraints between the two groups, were tested. These models are shown in Table 5-3, with the differences applied. It can be seen that the least restricted model, with all constraints removed (i.e., all of the free parameters were free to vary for each group), resulted in a χ^2 of 331.697 with 90 degrees of freedom ($p = 0.0$) in comparison to the most restricted model. Differences between successive models were statistically small until the lambdas were freed. Although the final model represented a statistically significant improvement in the fit of the model to the data in comparison to the most constrained model (χ^2 difference = 129.50, df = 24,

$p < .01$), it nevertheless remained a very poor representation of the covariance structures underlying the data, and further comparisons of young, young-old, and old-old using the proposed causal model were considered fruitless.

Although the final model did not acceptably fit the data, it was still possible to assess the relative magnitude of the betas in the young and old subjects by comparing the values of models with the betas constrained to be equal with models in which the betas were allowed to vary, using the same logic as in the model comparisons described above. That is, if the χ^2differences tests comparing models in which the betas for the young and old are constrained to be equal with models in which they are allowed to vary result in a significant improvement, inferences can be made about the relative magnitudes of the betas in the two groups. Table 5-4 summarizes the results of these model comparisons. It can be seen from these analyses that the betas appear to be statistically equivalent; hence the hypothesis that older adults are more reliant upon intact attention and concentration mechanisms for adequate memory performance was not supported by this analysis.

However, given the very poor fit of the model to the data in the initial analyses, any conclusions regarding the age comparability of these causal

parameters are undoubtedly premature; their apparent equivalence may be a statistical artifact. Inspection of the residuals and first derivatives from the LISREL analyses suggested that the three presumed endogenous constructs of memory, attention, and vigilance were not in fact comparably represented across the two age groups. Thus, if there were to be different numbers of factors in the two groups, or if the factors were differently constituted, it would be inappropriate to test a model requiring the same number of factors, when at least one of the groups required a different number of factors to describe the data. Therefore independent analyses in the two age groups were undertaken to clarify this issue. If it were to be discovered that subjects of different ages required different numbers of factors, with perhaps different constellations of factor loadings, such qualitative differences in factor structure would themselves be of significance.

Independent Analyses: Young Subjects

Independent exploratory factor analyses with Varimax and Promax rotations were undertaken using the EFAP program (Joreskog & Sorbom, 1978) in each age group in order to resolve the number of factors problem. Two, three, and four factors were examined. For the young subjects, two factors were found to be sufficient to account for the correlations among the variables, rather than the three that had been

hypothesized. Table 5-5 shows the factor loadings and factor correlations for the two factor Promax solution. This solution does not provide a readily interpretable pattern. The first factor consists of loadings for the three vigilance tasks and Identical Pictures, while the second consists of two memory tasks, word recognition, and the three attention tasks. Memory span loads on neither factor, reflecting its failure to correlate significantly with any task. Word recognition and Identical Pictures, presumed to measure vigilance and attention respectively, loaded on both factors, reflecting unexpected factorial complexity. It should be noted that good simple structure was not achieved, with six loadings falling between .1 and .3 (absolute values).

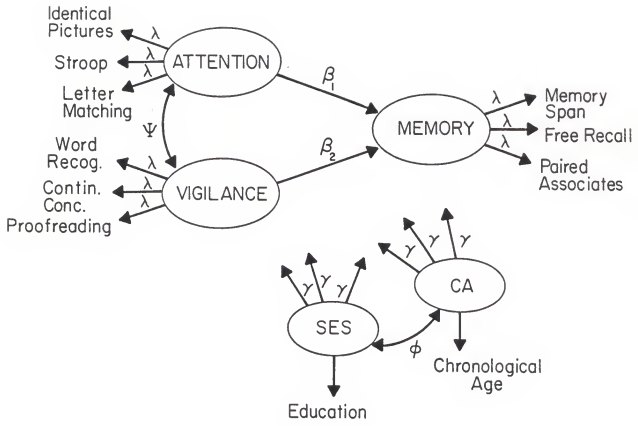

Figure 5-1

The Complete Model with Indicators

Table 5-1

Means, Standard Deviations, and Reliabilities for Two Age Groups

Task	Young[a]			Old[b,c]		
	X	s.d.	r	X	s.d.	r
Memory span	6.79	2.81	.63[d]	6.16	2.33	.63 [d]
Free recall	11.15	3.41	.58[f]	7.51	2.36	.59 [f]
Paired-associates	8.56	4.40	.83[e]	5.63	2.54	.83 [e]
Identical Pictures	64.59	14.71	.72[i]	40.89	9.97	.83 [i]
Stroop color-name	114.00	21.96	.63[h]	85.73	21.38	.63 [h]
Letter matching	118.62	19.59	.80[h]	94.16	25.25	.91 [h]
Word recognition	53.01	11.81	.80[f]	53.11	12.62	.80 [f]
Continuous conc.	22.70	6.01	.83[g]	22.62	5.84	.89 [g]
Proofreading	21.32	6.83	.50[f]	25.18	6.22	.70 [f]

a N = 98
b N = 140
c For memory span, paired associates, Stroop color-name, and word recognition, the reliabilities for the old subjects are assumed to be the same as for the young subjects, based on numerous reports in which reliabilities for different age groups did not vary systematically; in fact, the reliabilities for older subjects tend to be slightly higher than those for young subjects.
d Kelly, 1964.
e Educational Testing service, 1976, based on young adults.
f Estimated reliabilities based on the highest within-factor correlation.
g Estimated reliabilities based on the correlations for the two parts of each task.
h Willis, Cornelius, Blow, & Baltes, Note 1.
i Cunningham & Richardson, Note 3.

Table 5-2

Analyses of Variance for Nine Indicator Variables

Task	F	p
Memory span	3.453	.064
Free recall	95.097*	.000
Paired associates	41.829*	.000
Identical Pictures	219.565*	.000
Stroop color-name	131.082*	.000
Letter matching	66.485*	.000
Word recognition	.004	.952
Continuous concentration	.061	.804
Proofreading [a]	20.358*	.000

* $p < .01$
a Old outperformed young

Table 5-3

Hierarchical Model Comparisons

Model	χ^2	df	χ^2 diff.
Most constrained	461.197	114	-
Exogenous factor covariances freed	442.227	110	18.970*
Gammas freed	427.988	101	14.239*
Exogenous factor variances freed	408.875	98	19.113*
Betas freed	404.246	96	6.629
Least constrained (everything freed)	331.697	90	72.549**

* $p < .05$
** $p < .01$

Table 5-4

Model Comparisons to Assess Age Differences in the Betas

Model	χ^2 a	df
1. All betas free	331.697	90
2. $\beta_{1o} = \beta_{1y}$ $\beta_{2o} = \beta_{2y}$	334.881	92
3. $\beta_{1o} = \beta_{1y}$	334.703	91
4. $\beta_{2o} = \beta_{2y}$	334.321	91

a None of the χ^2 differences tests approached significance.

Table 5-5

Promax Solution for the Young Group
(χ^2 = 22.0, df = 19, p = .284, TRC = .997)

Factor loading matrix	1	2
Memory span	-.109	.223
Free recall	.076	.435
Paired associates	.028	.432
Word recognition	.346	.403
Proofreading	1.080	-.118
Continuous concentration	.477	.191
Identical Pictures	.364	.454
Stroop color-name	-.117	.787
Letter matching	.079	.657

Factor correlation matrix

	1	2
1	1.0	
2	.71	1.0

Independent Analyses: Old Subjects

The Promax solutions for the three and four factor solutions for the old subjects are shown in Tables 5-6 and 5-7. Although the three factor solution represents a statistically acceptable fit based on the probability level criterion ($p = .01$), the additional criterion of the Tucker Reliability Coefficient (TRC) being equal to or greater than .950 was not met. Hence the four factor solution may be a more adequate description of the structure of the data. A brief technical discussion of the Tucker Reliability Coefficient (Tucker & Lewis, 1973) and of the Scree Test, discussed below, are included in Appendix C.

The three factor solution shows an identifiable memory factor, a vigilance factor with additional loadings for memory span, Stroop color-name, and letter matching, and a factor comprised of word recognition, Identical Pictures, and Stroop color-name. Thus, even in a three factor solution, the three presumed constructs were not unequivocally identified. The four factor solution also shows an identifiable memory factor, an identifiable attention factor with an additional loading for continuous concentration, a factor with loadings for letter matching, memory span, and proofreading, and a doublet factor with loadings for word recognition and proofreading. Again, neither simple structure is very good, with eight loadings in

the three factor solution and ten loadings in the four factor solution falling between .1 and .3 (absolute values).

Secondary Independent Analyses

Supplementary independent restricted factor analyses were undertaken for each age group. Using LISREL, three factors were specified, with unities fixed for the factor variances and for one loading per factor. The memory tasks were constrained to load on only one factor, but the Stroop color-name, letter matching, and word recognition tasks were permitted to load on the other two factors because of their demonstrated factorial complexity. For the young subjects, a statistically acceptable result was achieved (χ^2= 33.34, df = 23, p = .075), but several of the parameters were anomalous and uninterpretable. For the older subjects, a statistically acceptable result was not achieved (χ^2= 61.32, df = 23, p = 0.0). Thus the results of these adjunctive analyses, although more statistically rigorous than the exploratory analyses reported above, continued to highlight the lack of age comparative construct validity.

A final statistical test was undertaken in order to address the number of factors issue. The Scree test (Gorsuch, 1983) is a traditional test that predates the more recent developments attributable to Joreskog (e.g., Joreskog, 1979). It has the benefit of being

independent of sample size, in contrast to χ^2 goodness-of-fit tests which are sensitive to sample size. The eigenvalues which are obtained from a factor analysis are plotted, from the largest to the smallest. The resulting curve is inspected for a break, which is generally detected after the largest proportions of variance are accounted for. Figures 5-2 and 5-3 show the Scree tests for the young and old subjects. It can be seen that two factors account for most of the variance in the young group and three account for most of the variance in the old group. However, the curves are rather ambiguous in contrast to those derived when a domain of variables is well known, in which case the break is typically sharper. Also, with more variables per factor, the eigenvalues are larger and the minimum number of factors accounting for the maximum amount of variance are more clearly defined. These results are in contradistinction to the results of the earlier exploratory analyses, and should only be considered as an illustration of an alternative approach to the number of factors problem. Overall, this series of analyses underscores the difficulty, often acknowledged among masters of factor analysis, in resolving the number of factors issue (e.g., Gorsuch, 1983).

Table 5-6

Promax Three Factor Solution for the Old Group
(x^2 = 26.18, df = 12, p = .01, TRC = .940)

Factor loading matrix	1	2	3
Memory span	-.238	.374	.422
Free recall	-.041	-.061	.836
Paired associates	.149	-.177	.815
Word recognition	.367	.499	.108
Proofreading	.008	.613	.181
Continuous concentration	.197	.439	.165
Identical Pictures	.959	.055	.011
Stroop color-name	.408	.363	.139
Letter matching	.062	.962	-.210

Factor correlation matrix

	1	2	3
1	1.0		
2	.63	1.0	
3	.47	.66	1.0

Table 5-7

Promax Four Factor Solution for the Old Group
(χ^2 = 9.07, df = 6, p = .17, TRC = .975)

Factor loading matrix	1	2	3	4
Memory span	-.073	-.150	.395	.551
Free recall	.024	.019	.725	.024
Paired associates	.034	.111	.747	-.071
Word recognition	.815	.191	.068	.033
Proofreading	.330	.142	.152	.300
Continuous conc.	-.021	.494	.155	.221
Identical Pictures	.241	.718	.055	-.102
Stroop color-name	.103	.831	.141	.061
Letter matching	.098	.465	-.236	.635

Factor correlation matrix

	1	2	3	4
1	1.0			
2	.64	1.0		
3	.43	.46	1.0	
4	.50	.47	.49	1.0

Given the evidence for different numbers of factors underlying the covariance matrices for the two age groups, further analyses of the proposed causal model are inappropriate. Although the apparent increase in the number of factors in a group of older subjects is unusual, it is not without precedent. White and Cunningham (Note 4) found such an increase in a set of information-processing tasks which may share properties with certain of the tasks included in the present study. In both cases it is necessary to conclude that age comparative construct validity must be demonstrated for the constructs of interest in order to make inferences, or test hypotheses, about differences in processes between groups of different ages. However, a further issue that warrants exploration is the differential age sensitivity of the tasks included in the present study.

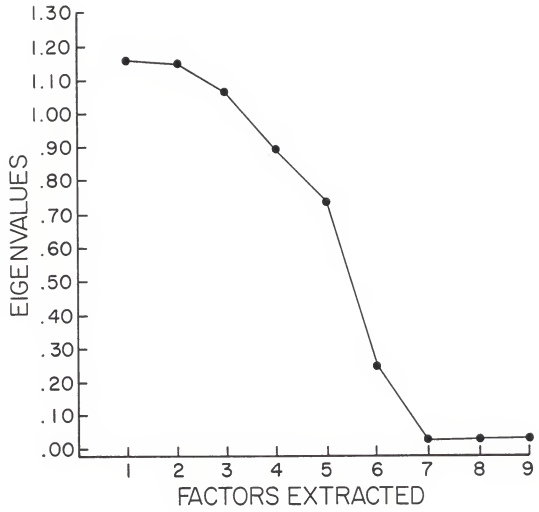

Figure 5-2

Scree Test for the Young Subjects

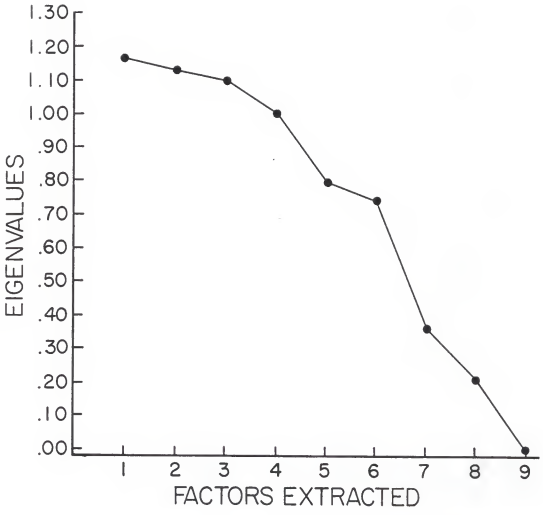

Figure 5-3

Scree Test for the Older Subjects

Age Sensitivity Analysis

In cognitive aging research, the issue is often to determine which abilities are the most age sensitive, i.e., which will discriminate best between age groups (Cunningham & White, Note 5). For example, of the WAIS subtests, Information is the least age sensitive and Digit Symbol is the most age sensitive (Botwinick, 1978). Pearson product moment correlations were computed between chronological age within the older group and the nine indicator tasks. Table 5-8 shows the resulting correlations, arranged in order of magnitude, and the percent of variance in performance accounted for by age differences. Thus, it can be seen that Stroop color-name is the most age sensitive task, followed by letter matching and Identical Pictures, while free recall, proofreading, and letter span are the least age sensitive of the tasks among the older subjects in the present study. While these results are similar to the results of the analyses of variance reported above, some differences are apparent. For example, although the entire old group outperformed the young group on proofreading, within the older group age differences are found, although they are small. Nevertheless, there is agreement from both analyses that cognitive processing tasks assumed to assess attention are sensitive to age.

Table 5-8

Correlations between Age and Memory, Attention, and Vigilance Tasks with the Proportion of Variance Accounted for by Age Differences among the Older Subjects

Task	Correlation	Percent Variance
Stroop color-name [a]	-.571**	32.6
Letter matching [a]	-.417**	17.4
Identical Pictures [a]	-.391**	15.3
Continuous concentration [c]	-.296**	7.7
Paired associates [b]	-.289**	7.4
Word recognition [c]	-.265**	6.0
Free recall [b]	-.192*	3.7
Proofreading [c]	-.186*	3.4
Memory span [b]	-.064	0.0

* $p < .05$
** $p < .01$
a Attention tasks
b Memory tasks
c Vigilance tasks

CHAPTER VI
DISCUSSION

Conclusions and Interpretations

The present study was designed to test the hypothesis that older adults are more dependent upon intact attentional mechanisms for efficient memory performance than young adults. The proposed model utilized constructs of attention and vigilance which were assumed to be causally prior to and causally related to the construct of memory. Because of the failure to demonstrate age comparative construct validity for the constructs of interest, it proved to be impossible to test this crucial hypothesis in a compelling manner. Although the model comparisons undertaken to assess the relative magnitudes of the betas showed them to be statistically equivalent, the initial failure to come even close to finding a suitable fit of the proposed model to the data renders any definitive conclusions regarding the equivalence of the processes in question tentative. Also, the finding of different numbers of factors in the two age groups in the supplementary analyses, as well as the failure to unequivocally identify the attention and vigilance

constructs, makes it impossible to undertake independent causal analyses in the two age groups.

It is necessary to demonstrate age comparative construct validity for tasks used in age comparative research. The finding of statistically significant mean age differences when the performance of young and older subjects is compared has little meaning unless it has been demonstrated that the tasks measure the same construct in the same manner in subjects of different ages. This issue has been dealt with extensively in the realm of intellectual abilities and age. Cunningham (1980a, 1980b, 1981) reported no age changes in the number of factors and no important shifts in salient factor loadings with increasing age. In contrast, this issue has been relatively ignored in the realm of cognitive processing measures. Robertson-Tchabo and Arenberg (1976) reported structural invariance for a set of memory and reaction time measures in subjects from 20 to 80 years of age; however, the sample sizes used in this study were too small for stability to be achieved. White and Cunningham (Note 4) reported an increase in the number of factors among a group of older subjects for a set of information processing tasks, although the three primary constructs of interest appeared to be comparably represented in the two age groups. Of the two additional factors found in the older subjects, one

appeared to be artifactual while the other appeared to represent strategy differences in spatial processing.

In the present study, the finding of two factors in the young subjects and between three and four in the older subjects represents an insurmountable obstacle to the testing of any hypotheses about differences in processes. The inclusion of adolescents as the young comparison group, while successful in increasing variability, may have been a confounding influence because of incomplete differentiation of abilities (Reinert, 1970). That is, abilities are thought to differentiate from birth to adulthood (in the factorial sense). The inclusion of young adolescents may have prevented the emergence of the three factors hypothesized; however, this is a very speculative suggestion, as differentiation is thought to be relatively complete for intellectual abilities by early adolescence, and this issue with information processing tasks has not been sufficiently explored. Nor did the three factor solution in the older subjects identify the three hypothesized factors, and the four factor solution was even less satisfactory from a construct validity viewpoint.

Part of the problem may lie in the selection of tasks. Ideally, a large selection of tasks presumed to measure the constructs of interest should be administered to large samples of young and older

adults. Factor analyses would then be undertaken to identify tasks which unequivocally measured the constructs of interest in each age group. This subset of tasks could then be utilized with new samples of young and older subjects in order to test the proposed model. However, such an undertaking would be prohibitive in terms of time and cost. Hence the tasks included in the present study were chosen because of their use in other research (the exception being the proofreading test), their face validity, and brevity and ease of administration in group settings.

Yet it is clear on the basis of the present results that these tasks did not measure the hypothesized constructs in the same way in the two groups. In the young subjects, the memory span test shares little variance with any other task, including the other memory tasks. In the older subjects, the memory span task not only shares variance with the two memory tests but also with word recognition and letter matching; thus performance in this task alone is reflecting different processes in subjects of different ages.

For the tasks presumed to reflect vigilance, age differences account for little variance. It is likely that these tasks were too short, or too easy, to tax sustained processing resources. In addition, their unexpected factorial complexity mitigated against any

demonstration of construct validity. In particular, the proofreading test appears to be a hidden vocabulary test; older adults frequently outperform young adults on vocabulary tests (Botwinick, 1978). Also, the operational distinction between attention and vigilance tasks appears to have been of little relevance, considering the factor analysis results; both word recognition and Stroop color-name have comparable loadings on the same two factors in the older subjects' three factor solution, indicating shared common properties with both presumed attention and presumed vigilance. It is entirely possible that with a more appropriate selection of tasks, including a preliminary demonstration of both the presence of the constructs of interest and age comparative construct validity, the original hypotheses could still be assessed in a rigorous manner.

Another contaminating influence might have been the different sampling schemes used for the two age groups. The young subjects were from a small rural school, were volunteered en masse by the school officials, and presumably had different levels of motivation than the older subjects, who volunteered their own services without any incentives. Thus the older subjects may have been superior to older adults in general, while the adolescents were probably more representative of the universe of adolescents. It

would have been interesting to include superior adolescents as the young comparison group, or a group of more homogeneous but probably more able and more motivated college students. Thus, motivational variability may have contributed to the performance variability in the young subjects, and hence indirectly accounted for some proportion of the ambiguous results.

In the present context, the finding of age differences in performance is only of interest to the degree that they conform to the previous literature; they can have little relevance for age differences in processes. The magnitude of age differences on the three memory tasks is entirely consistent with those previously reported (Craik, 1977). Similarly, the age differences found for Identical Pictures, Stroop color-name, and letter matching are likewise comparable to the results of other studies (Cunningham & White, Note 5; Willis, Cornelius, Blow, & Baltes, Note 1). The strength of the correlations between the three presumed attention tasks and age within the older group alone is consistent with the theory that aging of the central nervous system underlies changes in performance on speeded tests of cognitive processing; it is also consistent with the theory that central nervous system changes underly age differences in attention.

However, an alternative interpretation is possible regarding age differences in performance on the Stroop

color-name test. It has been suggested (Botwinick, 1978) that older adults may be more cautious and more rigid than young adults, especially when confronted with an unfamiliar task. Such cautiousness or rigidity may account for some of the observed age differences in the present case; this likelihood cannot be ruled out on the basis of the present study.

The lack of significant age differences for word recognition and continuous concentration, and the finding of the older subjects outperforming the young subjects in proofreading, while of little relevance for assessments of age differences in vigilance, are nevertheless of some interest in themselves. The word recognition and continuous concentration tasks were found by Willis, Cornelius, Blow, and Baltes, (Note 1) to assess aspects of sustained concentration; their tasks were slightly longer than the variants used in the present study. The level of performance found for all three tasks herein suggests that aspects of crystallized intelligence were assessed. Perhaps any verbal comprehension, or simple arithmetic task, if made to be sufficiently long, could also be considered to assess vigilance. The continuous performance test, described in Chapter 2, by contrast, assesses neither verbal nor arithmetic abilities. It is possible that assessing vigilance as a construct distinct from attention, using a pencil and paper test, is not

possible. In order to demonstrate that vigilance can be assessed in this manner, it is necessary to administer both pencil and paper variants and other more classical tests, such as the continuous performance and the Mackworth clock test, and determine whether correlation coefficients are of a sufficient magnitude to show convergent validity. Similarly, it would be important to demonstrate that pencil and paper instruments which are thought to assess attention show convergent validity when compared with the typical computer administered or card sorting attention tasks such as those reported in the literature (e.g., Hoyer & Plude, 1980; Rabbitt, 1965).

A final consideration is the impact on performance of behavioral slowing with age. The tasks showing the largest age differences were the most speeded, i.e., required working very quickly, while those showing the smallest age differences included very liberal time limits. The argument could be made that behavioral slowing is responsible for these results (Birren, Woods, & Williams, 1980). It is difficult to design a task in which the rate of performance is independent of the quality of performance; all behavior occurs in real time. The general notion of age-related behavioral slowing is not incompatible with age-related deficits in attention. The components of attention, such as focusing, attention-switching, and avoiding

distractors, take place in real time and are presumably tied to the integrity of the central nervous system in a similar manner to generalized behavioral slowing. If the components of attention are slowed with age, age differences in attention performance would result. Kausler (1982) concluded that behavioral slowing, in the general sense, cannot alone account for age differences in attentional processes, however.

Theoretical Implications

The failure to demonstrate age comparative construct validity for measures of attention and vigilance underscores the general ambiguity of the concepts. Attention has been discussed in terms of selective filtering and selective search (Hoyer & Plude, 1980), effortful versus automatic processing (Hasher & Zacks, 1979), and processing capacity or processing resources (Kahneman, 1973). Allport (1981) commented on the confusion of terminology that abounds in the literature, including the confusion of attention with consciousness. It would be very useful to achieve an integration of these approaches into an operationalizable theory of attention, which would facilitate assessments of age deficits in attention. A necessary adjunct to this strategy is the establishment of external criteria for the quantification of the concepts that emerge from this integration. For example, the processing resources orientation assesses

the amount of resources necessary for performance by the use of a dual task paradigm. If combining a presumed automatic processing task with a presumed controlled processing task does not reduce the performance of either in comparison with single task performance, the automatic processing task is assumed to require no resources; i.e., it is in fact automatic. This approach may be suitable for explaining selective attention tasks as well. Selective filtering tasks, on which age differences are reduced in comparison to selective search tasks, are those which require less of the limited processing resources available; this accounts for the performance of older adults, who are thought to have less resources available to them.

A similar approach is appropriate for vigilance. Parasuraman (1984) considered vigilance to be sustained attention; "specifically sustained attention over a period of time (from seconds to hours) for targets that appear infrequently and unpredictably" (p. 243). A processing resources orientation might equally well account for vigilance performance, and would have the additional benefit of introducing parsimony to the joint area of attention and vigilance.

Although the three memory tasks loaded on the same factor in both the three factor and the four factor solutions in the older subjects, it would not have been

surprising to have found them loading on different factors in a larger analysis including additional memory tasks. These three tasks assess different aspects of memory; the span task taps primary memory, free recall taps primary and secondary memory as well as rehearsal strategies, and paired associates taps associative learning. The Educational Testing Service (Ekstrom, French, & Harmon, 1976) reports separate factor for span memory and associative learning; Botwinick and Storandt (1974) identified separate factors for span memory, associative memory, and long term memory. Cunningham (Note 6) has emphasized the desirability of compiling a battery of memory tasks with demonstrated reliability and validity for purposes of clinical assessment in older adults. It is clear that such a goal is desirable for assessing attention and vigilance as well.

Causal modeling can be a powerful statistical tool in psychological research, but only when certain requirements are met. Comrey (1978) has documented the necessary steps to be taken in designing a factor analysis study. His remarks about selection of the variables are relevant in the present context. It is important to develop good, reliable, relatively pure measures of the constructs. Complex measures which contribute to two or more factors are to be avoided. As has been noted in the present study, the unexpected

factorial complexity encountered prevents any acceptable test of the hypotheses of interest from being undertaken. Any future attempts to assess age differences in causal processes must rely on demonstrated age comparative construct validity using univocal measures of the constructs of interest.

Future Directions

The proposition that age differences in attention and sustained concentration account for some proportion of age differences in memory merits further exploration. If experimental support can be achieved, intervention procedures could be developed to facilitate older individuals' using their limited processing resources in an optimal manner. At present, memory training procedures typically consist of introducing the use of mnemonic strategies, which themselves require much cognitive capacity. Activities which minimize processing resource requirements would be more useful for older adults. For example, Ackerman and Schneider (1984) demonstrated that practice has the effect of transforming cognitive processes that are initially effortful and resource consuming into automatic processes. This approach might prove to be useful with older adults, although the time required for this transformation to occur may be prohibitive for many older adults. Perhaps simply emphasizing the importance of focusing attention may be adequate, or

simple "focusing exercises" could be developed which might become automatized with use.

Intervention programs to maximize older adults' performance are becoming popular in aging research. The identification of three attention tasks which are sensitive to aging could be an important contribution to such efforts. Training older subjects to perform, e.g., Identical Pictures or Stroop color-name in an efficient manner may have the unexpected benefit of transfer of processing components to memory tasks such as free recall. Assuming the eventual demonstration of age comparative construct validity for attention and concentration tasks, perhaps an appropriate strategy would be to undertake an intervention study with near and far transfer-of-training assessments. In the present case, near transfer would be to vigilance tasks and far transfer would be to memory tasks. It is necessary to include young adults as a comparison group to assess whether transfer effects are age specific. This could clearly be a beneficial enterprise as an adjunct to the causal modeling approach and could have the benefit of being effective in addressing older adults' memory problems.

APPENDIX A

INFORMED CONSENT
UNIVERSITY OF FLORIDA

Participant's name _____

Address _____

Title of Project: Attention and Memory from Adolescence to Old Age

Principal Investigator: Nancy White, M.A.

This is a study to help better understand how memory and attention are related at different points in the life span. Each participant will be given a battery of tasks assessing attention and memory abilities. A brief questionnaire will also be given to assess socioeconomic status, and older subjects will be asked to complete a brief health status questionnaire.

Their will be no direct benefit to you for your participation, although it is anticipated that the experience of participating in research of this kind will be found to be enjoyable. None of the tasks should result in any discomfort on your part, so it is important for you to notify me at once if any discomfort is felt. Please ask any questions that might occur to you during the session. Your test scores will be kept strictly confidential in accord with legal limitations.

I, the undersigned, do understand the purpose of this project. The study proposed has been explained to me by the investigator whose name is signed below, and I agree to participate in the study. I also understand that I may withdraw at any time without prejudice.

I have read and understand the procedures described above. I agree to participate in the research, and I have received a copy of this form.

Participant's signature _____

I, the undersigned, have explained the study to the participant.

_____ / _____
Investigator's signature Date

Nancy White
Psychology Department

APPENDIX B

Uniformly Scaled Variance-Covariance Matrices
for Two Age Groups

Young Group

IP	1.467								
ST	.564	.987							
LM	.520	.453	.690						
WR	.676	.413	.329	.922					
PF	.838	.411	.441	.612	1.111				
CC	.491	.416	.308	.394	.648	1.054			
MS	.001	.161	.083	-.015	.041	.125	1.222		
FR	.541	.264	.387	.471	.452	.338	.213	1.444	
PA	.546	.357	.290	.385	.415	.410	.210	.452	1.648

Old Group

IP	.674								
ST	.593	1.009							
LM	.545	.704	1.216						
WR	.636	.659	.778	1.054					
PF	.401	.500	.614	.672	.922				
CC	.461	.579	.609	.565	.510	.963			
MS	.167	.258	.427	.313	.351	.298	.845		
FR	.226	.352	.262	.368	.349	.334	.316	.690	
PA	.263	.339	.244	.357	.270	.280	.306	.361	.548

Note: IP = Identical Pictures, ST = Stroop color-name, LM = Letter matching, WR = Word recognition, PF = Proofreading, CC = Continuous concentration, MS = Memory span, FR = Free recall, PA = Paired associates.

APPENDIX C

Technical Notes

Scree Test

In a factor analysis solution, characteristic roots, also known as eigenvalues, are computed which are associated with the factors. An eigenvalue is equal to the sum of the squared loadings on its associated factor, and is therefore a direct index of the amount of variance accounted for by the factor. During the factor extraction procedure, the factor with the largest associated eigenvalue is extracted first, followed successively by the factors with eigenvalues of decreasing size. Typically the factor extraction procedure stops when any additional factors would add relatively little to the information already extracted. An examination of a plot of the eigenvalues will generally show a "break" when most of the variance has been accounted for; the analogy is to the rubble at the bottom of a cliff (Gorsuch, 1983).

Tucker Reliability Coefficient

According to Tucker and Lewis (1973), a reliability coefficient may be defined by

$$m = \frac{Mo - Mm}{Mo - 1/n'm}$$

where Mo is the mean square for a model having zero common factors, Mm is the mean square for a model having m common factors, and n'm is the degrees of freedom. The reliability coefficient, m, may be interpreted as indicating how well a factor model with m common factors represents the covariances among the indicator variables for a given population. Lack of fit would indicate that the relations among the indicator variables are more complex than can be represented by m common factors. In general, the closer the reliability coefficient approaches unity, the more completely the covariances are assumed to be represented by the common factors.

REFERENCE NOTES

1. Willis, S. L., Cornelius, S.W., Blow, F.C., & Baltes, P. B. (1981). Training research in aging: Attentional processes. Unpublished manuscript, Pennsylvania State University.

2. Lansman, M. (1977). Pencil and paper measures of cognitive processes. Paper presented at the Western Psychological Association Meeting, Seattle.

3. Cunningham. W. R.,& Richardson, P. C. (1978). Age differences in factor structure of highly speeded intelligence tests. Paper presented at the American Psychological Association Meeting, Toronto.

4. White, N. A., & Cunningham, W. R. (1985). The age comparative construct validity of speeded cognitive factors. Under review, Multivariate Behavioral Research.

5. Cunningham, W. R., & White, N. A. (1984). Cognitive abilities and age: Where the action is. Paper presented at the American Psychological Association Meeting, Toronto.

6. Cunningham, W. R. (1985). Issues of reliability and validity. In L. W. Poon (Ed.), Clinical memory assessment in the aged. Washington, DC: American Psychological Association, in press.

REFERENCES

Ackerman, P. L., & Schneider, W. (1984). Individual differences in automatic and controlled processing. Champagne, Ill: University of Illinois.

Albert, M. S., & Kaplan, E., (1980) Organic implications of neurophysiological deficits in the elderly. In L. W. Poon, J. L. Fozard, L. S. Cermak, L.W. Thompson, & D. Arenberg (Eds.), New directions in memory and aging, (pp.403-432). Hillsdale, NJ: Erlbaum.

Allport, D. A., (1981) Attention and performance. In G. Claxton (Ed.), Cognitive psychology: New directions, (pp.112-153). London: Routledge & Kegan Paul.

Amaral, D. G., & Sinnamon, H. M. (1977). The locus coeruleus: Neurobiology of a central adrenergic nucleus. Progress in Neurobiology, 9, pp. 147-196.

Anders, T. R., Fozard, J. L., & Lillyquist, T. D. (1972). Effects of age upon retrieval from short-term memory. Developmental Psychology, 6, pp. 214-217.

Atkinson, R. C., & Shiffrin, R. M., (1968) Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), The psychology of learning and memory, (pp.89-195). New York: Academic Press.

Bakan, P. (1955). Discrimination decrement as a function of time in a prolonged vigil. Journal of Experimental Psychology, 50, pp. 387-390.

Beagley, H. A., & Sheldrake, M. B. (1978). Differences in brainstem response latency with age and sex. British Journal of Audiology, 12, pp. 69-77.

Beck, E. C., Dustman, R. E., Blusewicz, M. J., & Cannon, W. G., (1978) Cerebral evoked potentials and correlated neurophysiological changes in the human brain during aging: A comparison of alcohol and aging. In J. M. Ordy & K. R. Brizzee (Eds.), Sensory systems and communication in the elderly, (pp.203-226). New York: Raven Press.

Beck, E. C., Swanson, C., & Dustman, R. E. (1980). Long latency components of the visually evoked potential in man: Effects of aging. Experimental Aging Research, 6, pp. 523-545.

Bentler, P. M. (1980). Multivariate analysis with latent variables: Causal modeling. Annual Review of Psychology, 31, pp. 419-456.

Bentler, P. M., & Speckart, G. (1979). Models of attitude - behavior relations. Psychological Review, 86, pp. 452-464.

Bettner, L. G., Jarvik, L. F., & Blum, J. E. (1971). Stroop color-word test, nonpsychotic organic brain syndrome, and chromosome loss in aged twins. Journal of Gerontology, 26, pp. 458-469.

Birren, J. E., (1963) Psychophysiological relations. In J. E. Birren, R. N. Butler, S. W. Greenhouse, & L. Sokoloff, M. Yarrow (Eds.), Human aging: A biological and behavioral study, (pp.279-292). Bethesda, Md: U. S. Department of HEW.

Birren, J. E. (1974). Translations in gerontology - from lab to life: Psychophysiology and speed of response. American Psychologist, 29, pp. 808-815.

Birren, J. E., Woods, A. M., & Williams, M. V., (1980) Behavioral slowing with age: Causes, organization, and consequences. In L. W. Poon (Ed.), Aging in the 1980s, (pp.293-308). Washington, DC: American Psychological Assn.

Botwinick, J., (1977) Intellectual abilities. In J. E. Birren & K. W. Schaie (Eds.), Handbook of the psychology of aging, (pp.580-605). New York: Van Nostrand Reinhold.

Botwinick, J. (1978). Aging and behavior. New York: Springer.

Botwinick, J., & Storandt, M. (1974). Memory, related functions, and age. Springfield, Ill: Charles C. Thomas.

Botwinick, J., & Thompson, L. W. (1966). Components of reaction time in relation to age and sex. The Journal of Genetic Psychology, 108, pp. 175-183.

Brent, G. A., Smith, D. B. D., & Michaelewski, H. J. (1977). Differences in the evoked potential in young and old subjects during habituation and dishabituation procedures. Psychophysiology, 14, pp. 96-97.

Brizzee, K. R., Ordy, J. m., Knox, S. k., & Jirge, S. K., (1980) Morphology and aging in the brain. In G. J. Maletta & F. J. Pirozzolo (Eds.), The aging nervous system, (pp.10-39). New York: Praeger.

Broadbent, D. E. (1958). Perception and communication. London: Pergamon.

Brody, H., (1973) Aging of the vertebrate brain. In M. Rockstein (Ed.), Development and aging in the nervous system, (pp.121-134). New York: Academic Press.

Brody, H., (1976) An examination of cerebral cortex and brainstem aging. In R. D. Terry & S. Gershon (Eds.), Neurobiology of aging, (pp.177-182). New York: Raven Press.

Brown, A. L., (1979) Theories of memory and problems of development: Activity, growth, and knowledge. In L. S. Cermak & F. I. M. Craik (Eds.), Levels of processing in human memory, (pp.225-258). Hillsdale, NJ: Erlbaum.

Burke, D. M., & Light, L. L. (1981). Memory and aging: The role of retrieval processes. Psychological Bulletin, 90, pp. 513-546.

Cerella, J., Poon, L. W., & Fozard, J. L. (1982). Age and iconic read-out. Journal of Gerontology, 37, pp. 197-202.

Cohen, G. (1979). Language comprehension in old age. Cognitive Psychology, 11, pp. 412-429.

Comalli, P. E., Wapner, S., & Werner, H. (1962). Interference effects of Stroop color-word test in childhood, adulthood, and aging. Journal of Genetic Psychology, 100, pp. 47-53.

Comrey, A. L. (1978). Common methodological problems in factor analytic studies. Journal of Consulting and Clinical Psychology, 46, pp. 648-659.

Courchesne, E. (1978). Changes in P3 waves with event repetition: Long term effects on scalp distribution and amplitude. Electroencephalography and Clinical Neuropsychology, 45, pp. 754-766.

Craik, F. I. M., (1977) Age differences in human memory. In J. E. Birren & K. w. Schaie (Eds.), Handbook of the psychology of aging, (pp.384-420). New York: Van Nostrand Reinhold.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior, 11, pp. 671-684.

Craik, F. I. M., & Simon, E., (1980) Age differences in memory: The roles of attention and depth of processing. In L. W. Poon, J. L. Fozard, L. S. Cermak, L. W. Thompson, & D. Arenberg (Eds.), New directions in memory and aging, (pp.95-112). Hillsdale, NJ: Erlbaum.

Crowder, R. G., (1980) Echoic memory and the study of aging memory systems. In L. W. Poon, J. L. Fozard, L. S. Cermak, L. W. Thompson, & D. Arenberg (Eds.), New directions in memory and aging, (pp.181-204). Hillsdale, NJ: Erlbaum.

Cunningham, W. R., (1980a) Speed, age, and qualitative differences in cognitive functioning. In L. Poon (Ed.), Aging in the 1980s, (pp.327-331). Washington, DC: American Psychological Assn.

Cunningham, W. R. (1980b). Age comparative factor analysis of ability variables in adulthood and old age. Intelligence, 4, pp. 133-149.

Cunningham, W. R. (1981). Ability factor structure differences in adulthood and old age. Multivariate Behavioral Research, 16, pp. 3-22.

Damasio, A., (1979) The frontal lobes. In K. M. Heilman & E. Valenstein (Eds.), Clinical neuropsychology, (pp.360-412). New York: Oxford University Press.

Davies, D. R., & Griew, S., (1965) Age and vigilance. In A. Welford & J. E. Birren (Eds.), Behavior, aging, and the nervous system, (pp.54-59). Springfield, Ill: Charles C. Thomas.

Davies, D. R., & Tune, G. S. (1969). Human vigilance performance. New York: American Elsevier Publishing Co.

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. Psychological Review, 70, pp. 80-90.

Ekstrom, R. B., French, J. W., & Harmon, H. H. (1976). Manual for kit of factor-referenced cognitive tests. Princeton, NJ: Educational Testing Service.

Erber, J. T., Herman, T. G., & Botwinick, J. (1980). Age differences in memory as a function of depth of processing. Experimental Aging Research, 6, pp. 341-348.

Eysenck, M. W. (1974). Age differences in incidental learning. Developmental Psychology, 10, pp. 936-941.

Eysenck, M. W. (1978). Levels of processing: A critique. British Journal of Psychology, 69, pp. 157-169.

Farkas, M. S., & Hoyer, W. J. (1980). Processing consequences of perceptual grouping in selective attention. Journal of Gerontology, 35, pp. 207-216.

Flavell, J. H., Friedrichs, A. G., & Hoyt, J. D. (1970). Developmental changes in memory processes. Cognitive Psychology, 1, pp. 324-330.

Ford, J. M., Hink, R. F., Hopkins, W. F., Roth, W. T., Pfefferbaum, A., & Koppell, B. S. (1979). Age effects on event-related potentials in a selective attention task. Journal of Gerontology, 34, pp. 388-395.

Ford, J. M., & Pfefferbaum, A., (1980) The utility of brain potentials in determining age-related changes in central nervous system and cognitive functioning. In L. W. Poon (Ed.), Aging in the 1980s, (pp.115-124). Washington, DC: American Psychological Assn.

Ford, J. M., Roth, W. T., Mohs, R. C., Hopkins, W. F., & Koppell, B. S. (1979). Event-related potentials recorded from young and old adults during a memory retrieval task. Electroencephalography and Clinical Neuropsychology, 47, pp. 450-459.

Frankman, J. P., & Adams, J. A. (1962). Theories of vigilance. Psychological Bulletin, 59, pp. 257-272.

Goodin, D. S., Squires, K. C., Henderson, B. H., & Starr, A. (1978). Age-related variations in evoked potentials to auditory stimuli in normal human subjects. Electroencephalography and Clinical Neuropsychology, 44, pp. 447-458.

Gorsuch, R. L. (1983). Factor analysis. Hillsdale, NJ: Erlbaum.

Griew, S., & Davies, D. R. (1962). The effect of aging on auditory vigilance performance. Journal of Gerontology, 17, pp. 88-90.

Guyton, A. C. (1977). Basic human physiology. Philadelphia: W. B. Saunders Company.

Hansch, E. C., Syndulko, K., Pirozzolo, F. J., Cohen, S. N., Tourtelotte, W. W., & Potvin, A. R., (1980) Electrophysiological measurement in aging and dementia. In F. J. Pirozzolo & G. J. Maletta (Eds.), The aging nervous system, (pp.187-210). New York: Praeger.

Harkins, S. W., & Lenhardt, M., (1980) Brainstem auditory evoked potentials in the elderly. In L. W. Poon (Ed.), Aging in the 1980s, (pp.101-114). Washington, DC: American Psychological Assn.

Harkins, S. W., Moss, S. F., Thompson, L. W., & Nowlin, J. B. (1976). Relationship between central and autonomic nervous system activity: Correlates of psychomotor performance in elderly men. Experimental Aging Research, 2, pp. 409-423.

Harkins, S. W., Nowlin, J. B., Ramm, D., & Schroeder, S., (1974) Effects of age, sex, and time-on-watch on a brief continuous performance task. In E. Palmore (Ed.), Normal aging II, (pp.140-150). Durham, NC: Duke University Press.

Hartley, J. T., Harker, J. O., & Walsh, D. A., (1980) Contemporary issues and new directions in adult development of learning and memory. In (Ed.), Aging in the 1980s, (pp.239-252). Washington, DC: American Psychological Assn.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. Journal of Experimental Psychology: General, 108, pp. 356-388.

Hernandez-Peon, R., (1964) Attention, sleep, motivation, and behavior. In R. G. Heath (Ed.), The role of pleasure in behavior, (pp.214-229). New York: Harper & Row.

Hillyard, S. A., Picton, T., & Regan, D., (1978) Sensation, perception, and attention: Analysis using ERPs. In E. Calloway, P. Teuting, & S. Koslow (Eds.), Event-related brain potentials in man, (pp.256-279). New York: Academic Press.

Hillyard, S. A., & Woods, D. L., (1979) Electrophysiological analysis of human brain function. In M. S. Gazzaniga (Ed.), Handbook of behavioral neurobiology, (pp.345-378). New York: Plenum Publishing.

Horn, J. L., (1978) Human ability systems. In P. B. Baltes (Ed.), Life span development and behavior, (pp.221-256). New York: Academic Press.

Horn, J. L., (1982) The aging of human abilities. In J. B. Wolman (Ed.), Handbook of developmental psychology, (pp. 847-870). Englewood Cliffs, NJ: Prentice-Hall, Inc.

Horn, J. L., Donaldson, G., & Engstrom, R. (1981). Apprehension, memory, and fluid decline in adulthood. Research on aging, 3, pp. 33-84.

Horn, J. L., & McArdle, J. J., (1980) Perspectives on mathematical/statistical model building (MASMOB) in research on aging. In L. W. Poon (Ed.), Aging in the 1980s, (pp.503-541). Washington, DC: American Psychological Assn.

Hoyer, W. J., & Plude, D. J., (1980) Attention and perceptual processes in the study of cognitive aging. In L. W. Poon (Ed.), Aging in the 1980s, (pp.227-238). Washington, DC: American Psychological Assn.

Hultsch, D. F. (1971). Adult age differences in free classification and recall. Developmental Psychology, 4, pp. 338-342.

Hultsch, D. F. (1974). Learning to learn in adulthood. Journal of Gerontology, 29, pp. 302-308.

Hunter, B., Zornetzer, S. F., Jarvik, M. E., & McGaugh, J. L., (1977) Modulation of learning and memory: Effects of drugs influencing neurotransmitters. In L. L. Iverson, S. D. Iverson, & S. Snyder (Eds.), Handbook of psychopharmacology, (pp.538-552). New York: Plenum Press.

Inglis, J., & Caird, W. K. (1963). Age differences in successive responses to simultaneous stimulation. Canadian Journal of Psychology, 17, pp. 98-105.

James, W. (1890). The principles of psychology. New York: Holt.

Joreskog, J. G., & Sorbom, D. (1978). EFAP-II: Exploratory factor analysis program. Chicago: International Education Service.

Joreskog, K. G. (1979). Advances in factor analysis and structural equation models. Cambridge, Mass.: Abt Books.

Joreskog, K. G., & Sorbom, D. (1978). LISREL: Analysis of linear structural relationships by the method of maximum likelihood. Chicago: National Educational Resources.

Kahn, R. L., Zarit, S. H., Hilbert, N. M., & Niederehe, G. A. (1975). Memory complaint and impairment in the aged: The effect of depression and altered brain function. Archives of General Psychiatry, 32, pp. 1560-1573.

Kahneman, D. (1973). Attention and effort. Englewood Cliffs, NJ: Prentice-Hall.

Kausler, D. H., & Puckett, J. M. (1981). Adult age differences in memory for sex of voice. Journal of Gerontology, 36, pp. 44-50.

Keele, S. W. (1973). Attention and human performance. Pacific Palisades,CA: Goodyear.

Kelley, H. P. (1964). Memory abilities: A factor analysis. Psychometric Monographs, 11, pp. 1-53.

Kenny, D. A. (1979). Correlation and causation. New York: John Wiley & Sons.

Kinchla, R. A., & Wolfe, J. M. (1979). The order of visual processing: "Top-down", "bottom-up", or "middle-out". Perception & Psychophysics, 25, pp. 225-231.

Kinsbourne, M., (1980) Attentional dysfunctions and the elderly: Theoretical models and research perspectives. In L. W. Poon, J. L. Fozard, L. S. Cermak, L. W. Thompson, & D. Arenberg (Eds.), New directions in memory and aging, (pp.113-130). Hillsdale, NJ: Erlbaum.

Klatzky, R. L. (1980). Human memory. San Francisco: W. H. Freeman and Company.

Kubanis, P., & Zornetzer, S. F. (1981). Age-related behavioral and neurobiological changes: A review with an emphasis on memory. Behavioral and Neural Biology, 31, pp. 115-172.

Labouvie-Vief, G., & Schell, D. A., (1982) Learning and memory in later life. In J. B. Wolman (Ed.), Handbook of developmental psychology, (pp.828-846). Englewood Cliffs, NJ: Prentice-Hall, Inc.

Loveless, N. E., & Sanford, A. J. (1974). Effects of age on the contingent negative variation and preparatory set in a reaction-time task. Journal of Gerontology, 29, pp. 52-63.

Luria, A. R. (1973). The working brain. New York: Basic Books.

Mackworth, J. F. (1968). Vigilance, arousal, and habituation. Psychological Review, 75, pp. 308-322.

Mackworth, N. H. (1961). Researches on the measurement of human performance. New York: Dover Publications.

Madden, D. J. (1984). Data-driven and memory-driven selective attention in visual search. Journal of Gerontology, 39, pp. 72-78.

Madden, D. J., & Nebes, R. D. (1980). Aging and the development of automaticity in visual search. Developmental Psychology, 16, pp. 377-384.

Marsh, G. R., & Thompson, L. W. (1973). Effects of age on the contingent negative variation in a pitch discrimination task. Journal of Gerontology, 28, pp. 55-62.

Maruyama, G., & McGarvey, B. (1980). Evaluating causal models: An application of maximum likelihood analysis of structural equations. Psychological Bulletin, 87, pp. 467-469.

Mason, S. E. (1979). The effects of orienting tasks on recall and recognition performance of subjects differing in age. Developmental Psychology, 15, pp. 467-469.

McGrath, J. J., (1963) Irrelevant stimulation and vigilance performance. In D. N. Buckner & J. J. McGrath (Eds.), Vigilance: A symposium, (pp.3-18). New York: McGraw-Hill Book Company.

Mergler, N. L., Dusek, J. B., & Hoyer, W. J. (1977). Central/incidental recall and selective attention in young and elderly adults. Experimental Aging Research, 3, pp. 49-60.

Michaelewski, H. J., Patterson, J. V., Bowman, T. E., Litzelman, D. K., & Thompson, L. W. (1982). A comparison of the emitted late positive potential in older and young adults. Journal of Gerontology, 37, pp. 52-58.

Michaelewski, H. J., Thompson, L. W., Smith, D. B., Patterson, J. V., Bowman, T. E., Litzelman, D., & Brent, G. (1980). Reduced frontal activity in the elderly: Age differences in the contingent negative variation (CNV). Journal of Gerontology, 35, pp. 542-549.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review, 63, pp. 81-97.

Miller, J. (1979). Cognitive influences on perceptual processing. Journal of Experimental Psychology: Human Perception and Performance, 5, pp. 546-562.

Milner, P. M. (1970). Physiological psychology. New York: Holt, Rineheart, and Winston.

Nauta, W. J. (1971). The problem of the frontal lobe: A reinterpretation. Journal of Psychiatric Research, 8, pp. 167-187.

Navon, D., & Gopher, D. (1979). On the economy of the human processing system. Psychological Review, 86, pp. 214-255.

Neisser, U. (1967). Cognitive psychology. New York: Appleton-Century-Crofts.

Norman, D. A. (1968). Toward a theory of memory and attention. Psychological Review, 75, pp. 522-536.

Norman, D. A., & Bobrow, D. G. (1975). On data limited and resource limited processes. Cognitive Psychology, 7, pp. 44-64.

Nunnally, J. (1978). Psychometric theory. New York: McGraw-Hill Book Company.

Panek, P. E., Barrett, G. V., Sterns, H. L., & Alexander, R. A. (1977). Age changes in perceptual information processing ability with regard to driving. Experimental Aging Research, 3, pp. 387-450.

Parasuraman, R., (1984) Sustained attention in detection and discrimination. In R. Parasuraman & D. R. Davies (Eds.), Varieties of attention, (pp.243-272). New York: Academic Press.

Patterson, J. V., Michaelewski, H. J., Thompson, L. W., Bowman, T. E., & Litzelman, D. K. (1981). Age and sex differences in the human auditory brainstem response. Journal of Gerontology, 36, pp. 455-462.

Perlmutter, M. (1978). What is memory aging the aging of?. Developmental Psychology, 14, pp. 330-345.

Perlmutter, M. (1979). Age differences in adults' free recall, cued recall, and recognition. Journal of Gerontology, 34, pp. 533-539.

Pillsbury, W. B. (1908). Attention. London: Swan Sonnenschein & Co., Ltd.

Plude, D. J., & Hoyer, W. J. (1981). Adult age differences in visual search as a function of stimulus mapping and cognitive load. Journal of Gerontology, 36, pp. 598-604.

Poon, L. W., Fozard, J. L., Cermak, L. S., Arenberg, D., & Thompson, L. W. (1980). New directions in memory and aging. Hillsdale, NJ: Erlbaum.

Posner, M. I. (1978). Chronometric explorations of the mind. Hillsdale, NJ: Erlbaum.

Posner, M. I., & Snyder, C. R., (1975) Attention and cognitive control. In R. L. Solso (Ed.), Information processing and cognition, (pp.55-85). Potomac, Md: Erlbaum.

Rabbitt, P. M. (1965). An age decrement in the ability to ignore irrelevant information. Journal of Gerontology, 20, pp. 233-238.

Rabbitt, P. M., (1979) Some experiments and a model for changes in attentional selectivity with old age. In F. Hoffmeister & C. Muller (Eds.), Brain function in old age: Evaluation of changes and disorders, (pp.82-94). New York: Springer-Verlag.

Rees, J. N., & Botwinick, J. (1971). Detection and decision factors in auditory behavior in the elderly. Journal of Gerontology, 26, pp. 133-136.

Reinert, G., (1970) Comparative factor analytic studies of intelligence throughout the human life-span. In L. R. Goulet & P. B. Baltes (Eds.), Life-span developmental psychology: Research and theory, (pp.115-145). New York: Academic Press.

Robertson-Tchabo, E. A., & Arenberg, D. (1976). Age differences in cognition in healthy educated men: A factor analysis of experimental factors. Experimental Aging Research, 2, pp. 75-79.

Salthouse, T. A., (1980) Age and memory: Strategies for localizing the loss. In L. W. Poon, J. L. Fozard, L. S. Cermak, L. W. Thompson, & D. Arenberg (Eds.), New directions in memory and aging, (pp.47-66). Hillsdale, NJ: Erlbaum.

Sanders, R. E., Murphy, M. D., Schmitt, F. A., & Walsh, K. K. (1980). Age differences in free recall rehearsal strategies. Journal of Gerontology, 35, pp. 550-558.

Schaie, J. P., & Syndulko, K. (1978). Age differences in cortical activity associated with preparation to respond. International Journal of Behavioral Development, 1, pp. 255-261.

Scheibel, M. E., & Scheibel, A. B., (1975) Structural changes in the aging brain. In H. Brody, D. Harman, & J. M. Ordy (Eds.), Aging, (pp.11-38). New York: Raven Press.

Schneider, W., & Shiffrin, R. m. (1977). Controlled and automatic information processing: I. Detection, search, and attention. Psychological Review, 84, pp. 1-66.

Schonfield, D., & Robertson, B. A. (1966). Memory storage and aging. Canadian Journal of Psychology, 20, pp. 228-236.

Smith, A. D. (1977). Adult age differences in cued recall. Developmental Psychology, 13, pp. 326-331.

Smith, A. D., (1980) Age differences in encoding, storage, and retrieval. In L. W. Poon, J. L. Fozard, L. S. Cermak, L. W. Thompson, & D. Arenberg (Eds.), New directions in memory and aging, (pp.23-46). Hillsdale, NJ: Erlbaum.

Smith, D. B., Thompson, L. W., & Michaelewski, H. J., (1980) Average evoked potential research in adult aging - Status and prospects. In L. W. Poon (Ed.), Aging in the 1980s, (pp.135-154). Washington, DC: American Psychological Assn.

Sokolov, Y. E. (1963). Perception and the conditioned reflex. New York: MacMillan.

Sorbom, D., & Joreskog, K. G. (1976). COFAMM: Confirmatory factor analysis with model modification. Chicago: National Educational Resources.

Squires, K. C., Chippendale, T. J., Wrege, K. S., Goodin, D. S., & Starr, A., (1980) Electrophysiological assessment of mental function in aging and dementia. In L. W. Poon (Ed.), Aging in the 1980s, (pp.125-134). Washington, DC: American Psychological Assn.

Squires, N., Squires, K. C., & Hillyard, S. A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography and Clinical Neuropsychology, 38, pp. 387-401.

Starr, A., & Hamilton, A. E. (1976). Correlation between confirmed sites of neurological lesions and abnormalities of far-field auditory brainstem responses. Electroencephalography and Clinical Neuropsychology, 41, pp. 595-608.

Sternberg, S. (1969). Memory-scanning: Mental processes revealed by reaction-time experiments. American Scientist, 57, pp. 421-456.

Street, W. J., Perry, N. W., & Cunningham, W. R. (1976). A factor analysis of visual evoked potentials. Psychophysiology, 13, pp. 352-356.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 18, pp. 643-661.

Tecce, J. J. (1972). Contingent negative variation (CNV) and psychological processes in man. Psychological Bulletin, 77, pp. 73-108.

Terry, R. D., (1978) Physical changes in the aging brain. In C. E. Behnke, J. A. Finch, & G. B. Moment (Eds.), The biology of aging, (pp.43-84). New York: Plenum.

Thompson, L. W., (1980) Periodic "lapses" in attention: A possible correlate of memory impairments in the elderly. In L. W. Poon, J. L. Fozard, L. S. Cermak, L. W. Thompson, & D. Arenberg (Eds.), New directions in memory and aging, (pp.239-242). Hillsdale, NJ: Erlbaum.

Thompson, L. W., Opton, E., & Cohen, L. D. (1963). Effects of age, presentation speed, and sensory modality on performance of a "vigilance" task. Journal of Gerontology, 18, pp. 366-369.

Thorndike, E. L., & Lorge, I. (1944). The teacher's book of 30,000 words. New York: Teacher's College Press.

Treat, N. J., & Reese, H. W. (1976). Age, pacing, and imagery in paired-associate learning. Developmental Psychology, 12, pp. 119-124.

Treisman, A. M. (1960). Contextual cues in selective listening. Quarterly Journal of Experimental Psychology, 12, pp. 242-248.

Treisman, A. M. (1964). Monitoring and storage of irrelevant messages in selective attention. Journal of Verbal Learning and Verbal Behavior, 3, pp. 449-459.

Tucker, L. R., & Lewis, C. (1973). A reliability coefficient for maximum likelihood factor analysis. Psychometrika, 38, pp. 1-10.

Walsh, D. A., & Prasse, M. J., (1980) Iconic memory and attentional processes in the aged. In L. W. Poon, J. L. Fozard, L. S. Cermak, L. W. Thompson, & D. Arenberg (Eds.), New directions in memory and aging, (pp.153-180). Hillsdale, NJ: Erlbaum.

Walsh, D. A., & Thompson, L. W. (1978). Age differences in visual sensory memory. Journal of Gerontology, 33, pp. 383-387.

Walter, W. G., (1964) The convergence and interaction of visual, auditory, and tactile responses in human non-specific cortex. In N. R. Whipple (Ed.), Sensory evoked response in man, (pp.321-334). New York: The New York Academy of Sciences.

Walter, W. G., Cooper, R., Aldridge, V. J., McCallum, W. C., & Winter, A. L. (1964). Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. Nature, 203, pp. 380-384.

Warren, R. E. (1972). Stimulus encoding and memory. Journal of Experimental Psychology, 94, pp. 90-100.

Waugh, N. C., & Barr, R. A., (1980) Memory and mental tempo. In L. W. Poon, J. L. Fozard, L. S. Cermak, L. W. Thompson, & D. Arenberg (Eds.), New directions in memory and aging, (pp.251-260). Hillsdale, NJ: Erlbaum.

Waugh, N. C., & Norman, D. A. (1965). Primary memory. Psychological Review, 72, pp. 89-104.

Weerts, T. C., & Lang, P. J. (1973). The effects of eye fixation and stimulus and response location on the contingent negative variation. Biological Psychology, 1, pp. 1-19.

Whitbourne, S. K., & Slevin, A. E. (1978). Imagery and sentence retention in young and elderly adults. Journal of Genetic Psychology, 133, pp. 287-298.

Wright, L. L., & Elias, J. W. (1979). Age differences in the effects of perceptual noise. Journal of Gerontology, 34, pp. 704-708.

Wright, R. E. (1981). Aging, divided attention, and processing capacity. Journal of Gerontology, 36, pp. 605-614.

Zelinski, E. M., Walsh, D. A., & Thompson, L. W. (1978). Orienting task effects on EDR and free recall in three age groups. Journal of Gerontology, 33, pp. 239-245.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Walter R. Cunningham, Chairman
Associate Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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